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An Economic Framework for Analyzing DoD Profit Policy

William P. Rogerson

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Assistant Secretary of Defense
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PREFACE

This report is part of a larger project on the economics of defense acquisition. It was sponsored by the Assistant Secretary of Defense, Program Analysis and Evaluation, and was carried out in the Acquisition and Support Policy Program of RAND's National Defense Research Institute, a federally funded research and development center supported by the Secretary of Defense and the Joint Staff. The publication should be of interest to researchers and policymakers who are concerned about the effects of profit policy and cost-accounting regulations on system costs, investment incentives, input utilization, and contractor profits.

SUMMARY

INTRODUCTION

Many items purchased by the Department of Defense (DoD) are one of a kind and involve very advanced and specialized technology. As a consequence, the DoD often finds itself procuring items from a sole source. When competition cannot be used to determine a price for the product, the DoD must instead attempt to determine a fair price for it based upon the anticipated costs of producing it. In a noncompetitive procurement, the firm must submit extremely detailed estimates of its anticipated costs of production. DoD negotiators use this information and any other available information to create their own estimate of the cost of production. A complicated set of regulations, collectively referred to as profit policy, are then used to calculate a "profit" for the contract. The negotiators' estimate of a fair price consists of the anticipated cost plus the profit. Armed with these calculations, the negotiators then attempt to obtain a price as close to the calculated fair price as possible.

This report provides an economic analysis of the regulations used to calculate the part of the fair price referred to as profit. It argues that profit actually consists of many conceptually distinct components, each performing a distinct economic function. Furthermore, economic analysis generates a surprising amount of guidance on how each component should be calculated to optimally perform its function. The form of the current regulations is optimal in some respects but requires significant revision in others. Thus, this report provides an overall economic framework in which to understand the function of profit in the procurement process. Such understanding is, of course, a necessary precondition to a debate over modifying it.

From an economic perspective, the profit awarded on procurement contracts can be divided into two broad categories. First, many economic costs of production are not recognized as costs in government accounting regulations. Thus, reimbursement for these unrecognized costs is called profit. Such costs include the cost of accepting risk when a contract is signed, the cost of working capital, and the cost of facilities capital. It will be shown that there are a number of other categories of unrecognized costs as well. A separate component of profit must be calculated to reimburse firms for each category of unrecognized costs if a price is to be calculated that fully reimburses the firm for all of its costs.

The second category of profit awarded on procurement contracts actually consists of economic profit, i.e., payment of money in excess of the economic costs of performing the contract. The regulations explicitly identify one small subcategory of such profit payments, namely, payment of profit for specific observed actions of the contractor, such as implementing a good socioeconomic program or implementing a more accurate cost-estimating system. However, the regulations do not explicitly acknowledge the most important subcategory of such profit payments—payment of economic profit to provide firms with an incentive to increase their efforts toward innovation. This report argues that profit policy is and necessarily must be structured to provide economic profit on contracts to serve as prizes for innovation.

Therefore the central theme of this report is that profit policy regulations should be analyzed in the context of an economic theory that explicitly identifies the economic functions of profit. The most basic distinction is the one between profit meant as reimbursement for unrecognized economic costs and economic profit. Within the former category, policymakers need to explicitly identify and analyze the various classes of unrecognized economic costs. Then, the regulations should identify each class of unrecognized cost as a separate component of profit and provide the contracting officer with directions on how its value should be estimated. With respect to the latter category, policymakers need to explicitly decide if they wish to use economic profit to create incentives for firms to adopt particular behavior patterns or to exert more effort toward innovation. In particular, they must address the question of whether some method other than awarding economic profit could be used to accomplish the same objective more cheaply. If no cheaper method exists, the manner in which the regulations award profit should be carefully structured to yield the maximum impact on firms' behavior for the minimum cost.

This report lays the foundations for such an economic approach to profit policy regulations by attempting to systematically identify the possible categories of unrecognized costs and incentive schemes that could exist and then employing fairly simple economic theory to explain how to calculate profit in each case. In the case of economic profit as an incentive scheme, the question of whether these are useful schemes is also addressed. A very close connection to the actual regulations is maintained throughout the entire analysis in two respects. The current regulations were read very carefully in an attempt to ferret out all possible unrecognized costs and incentive schemes that the regulations might possibly mention. And, whenever a particular theoretical component of profit is discussed, the relevant

portion of the regulations is always identified and a comparison made between the theoretically correct rule and the actual rule.

This report does not provide a "complete" analysis of the regulations in two respects. First, it ignores a number of issues that may complicate the role of profit policy. Second, it does not actually state what the correct level of profit should be in all components of the regulations. In particular, the question of how to calculate the correct values for three important parameters is not fully answered. These are the contract risk premium, the facilities capital risk premium, and the innovation incentive. However, it is possible to infer the values of these parameters implicitly used in the current regulations. The report concludes in Sec. 14 by presenting a proposed revision of profit policy regulations consistent with the analysis of the preceding sections. The result is a set of regulations that are conceptually clear and straightforward, that have the correct economic form, that have the correct level for the risk-free rate, and that use the levels for the risk premiums and innovation incentive implicit in the current regulations.

This report's major accomplishment is to clarify the economic functions being performed by various components of profit, to suggest a number of important qualitative properties that the optimal rules should exhibit, and to infer what levels of profit the current regulations seem to be assigning to various components. Thus, a very clear and economically rational framework is created for further analysis. This further analysis should attempt to address the question of optimal levels of profit and to consider the implications of relaxing a number of simplifying assumptions.

CURRENT PROFIT POLICY

DoD contracts usually specify that the firm's revenues will be a linear function of *ex post* cost where the function has a slope between 0 and 1. These contracts specify a target cost, target profit, and sharing ratio. The firm will earn the target profit if *ex post* cost precisely equals the target cost. The sharing ratio specifies the share of cost overruns and underruns that will be borne by the firm. Profit policy regulations instruct the contracting officer how to determine target profit for a contract. Since profit policy regulations focus exclusively on expected or target profit, the term "profit" will always be used to mean "expected profit" in this report.

Table S.1 summarizes current profit policy regulations. The cost of the contract is denoted by *C*. DoD procurement regulations essen-

Table S.1
Current Profit Policy

Profit Component	Normal Value, %	Allowable Range, %	Base That % Is Applied To
Performance risk			
Technical Risk	1.2	0.6 to 1.8	C
Management	1.2	0.6 to 1.8	C
Cost control	1.6	0.8 to 2.4	C
Total	4	2 to 6	C
Contract risk			
FFP	3	2 to 4	C
FPI or CPI	1	0 to 2	C
CPFF	0.5	0 to 1	C
Facilities capital			
Profits received by all contracts	Treasury rate	Treasury rate	ℓK
Standard extra profit			
Land	0	0	ℓK_L
Buildings	15	10 to 20	ℓK_B
Equipment	35	20 to 50	ℓK_E
Alternative extra profit	2	2	C
Working capital			
Cost-type contracts	0	0	—
Fixed-price contracts with no progress payments	2	2	C
Fixed-price contracts with progress payments	Treasury rate	Treasury rate	$L(\ell)(1 - \alpha)C$

tially use the term cost in the same fashion as accountants do. Cost thus consists of operating cost plus depreciation of physical capital. The length of the contract in years is denoted by ℓ . The book value of all physical capital used on the contract is denoted by K . This can be broken down into land, buildings, and equipment. These book values are denoted, respectively, by K_L , K_B , and K_E . All the above parameters are likely to be uncertain at the time of contracting and should be interpreted as the contracting officer's estimate of their value.

Every contract signed by the DoD is formally classified as a fixed-price-type or cost-type contract. This terminology is somewhat misleading because a contract's type is not formally dependent on the cost-sharing ratio of the contract. Either type of contract may have the firm bear any share of the risk between 0 and 1. A fixed-price-

type contract where the firm bears all of the risk is called firm fixed price (FFP); other fixed-price contracts are called fixed price incentive (FPI). A cost-type contract where the DoD bears all of the risk is called cost plus fixed fee (CPFF); other cost-type contracts are called cost plus incentive fee (CPIF). For the purposes of this report, the major difference between these two contract types is in the nature of progress payments. Progress payments are payments made to the firm over the duration of the contract to reimburse it for costs as they are incurred. The progress payment rate is defined as the fraction of costs that are immediately reimbursed. Cost-type contracts are assigned a progress payment rate of 1, i.e., they receive complete reimbursement. Fixed-price-type contracts are assigned a lower progress payment rate. Although there are a number of exceptions, most fixed-price contracts are assigned a "normal" rate, specified in the regulations, which is changed from time to time. The current rate is 0.8. In general, let α denote the progress payment rate.

As can be seen from Table S.1, profit is broken into four components. Many components are further broken down into subcomponents. The method for calculating profit for a given component or subcomponent is always the same. The regulations specify a "base" for the profit calculation. This may be, for example, total expected cost or the net book value of facilities capital, depending on the component. Then, the contracting officer calculates profit by selecting a percentage to apply to the base. The regulations always specify a normal value for the percentage and an allowable range. Then a variety of factors are listed and discussed that affect how large a value the contracting officer should choose from the allowable range.¹

The four components of profit will now be described in more detail. The performance profit section of the regulations is entitled "performance *risk*." However, this term is a misnomer, since the profit is broken into three subcomponents and only one of these involves risk. Therefore, it will be called "performance *profit*" here. From reading the descriptions in the regulations of factors that should

¹Table S.1 has been simplified in one respect. In almost all cases where the table specifies C as the base, the regulations in reality specify C net of general and administrative (G&A) costs as the base. G&A consists basically of central management costs. There may be some reasons related to incentives for cost minimization in the presence of joint costs to exclude G&A from the profit calculation. However, these issues are not explored here. Thus, whether or not G&A is included is irrelevant in this analysis. For expositional simplicity, this summary will describe the regulations as though there are no G&A costs. Under this assumption, the regulations can be viewed as specifying a base of C as stated in Table S.1. In the main body of the report, a slightly more complicated algebraic correction will be made.

cause the contracting officer to choose a high or low value for each subcomponent, one can attempt to infer the nature of profit that each subcomponent is attempting to calculate. The technical risk component is clearly meant to reimburse the firm for bearing risk, since the value awarded is supposed to increase as the uncertainty of project costs increases. However, no simple conclusions are possible about the other two subcomponents. The descriptions contain a hodgepodge of factors that do not immediately suggest any particular theory of profit. A major task of this report is to attempt to make economic sense out of the variety of factors listed under these two subcomponents.

All contracts are also given a second profit calculated as a percentage of cost. Once again, this is described as a return to risk but this time it is labeled a return to "contract risk." The difference between this component and the technical risk component is that the contract risk component is meant to respond to the amount of risk-sharing in the contract. Thus, a normal value and allowable range are specified for various types of contracts. The normal value and allowable ranges shift upward as the firm bears a greater share of the risk of cost overruns and underruns. In contrast, the technical risk calculation is supposed to be totally independent of the firm's share of the risk.

All facilities capital used on a contract receives profit of the treasury rate multiplied by the net book value of the capital for every year the facilities capital is used on the contract. That is, a percentage equal to the treasury rate is applied to a base of \$K. The treasury rate is an interest rate published semiannually by the Treasury Department and is supposed to reflect "current private commercial rates of interest for new loans maturing in approximately five years." This report shows that the treasury rate has historically been almost perfectly predicted by adding 1 percent to the then-current yield on intermediate-term government bonds.

The regulations instruct that an additional return to facilities capital be given in addition to the treasury rate. The standard method for calculating this additional return is as follows. Different returns are allowed for different assets, depending on whether they are land, buildings, or equipment. As usual, a normal value and an allowable range are specified. An alternative rule is used for firms that primarily perform research and development or service functions. They will typically have very small investments in facilities capital. For them, the regulations allow the negotiator to give the contractor an extra 2 percent of cost as profit instead of using the standard rule.

The final component of profit—working capital—is meant to reimburse the firm for the cost of financing work in progress. Cost-type contracts receive 100 percent progress payments and thus no working capital profit is paid. Extremely short or small fixed-price contracts may receive no progress payments. These receive a working capital profit equal to 2 percent of cost. Most fixed-price contracts receive progress payments. These receive a working capital profit equal to the treasury rate times the base

$$(1 - \alpha)L(\ell)C, \quad (\text{S.1})$$

where $L(\ell)$ is a function of contract length, ℓ , essentially given by

$$L = \begin{cases} 0.4 & , \quad \ell \leq 1.5 \\ -0.35 + 0.5\ell & , \quad 1.5 \leq \ell \leq 6.5 \\ 2.9 & , \quad \ell \geq 6.5 \end{cases} \quad (\text{S.2})$$

That is, it equals the 45° line shifted down by 0.35, with a floor of 0.4 and a ceiling of 2.9. The function $L(\ell)$ is called the length factor.

THEORY OF CONTRACT RISK AND WORKING CAPITAL

Many important economic insights derived in this report concern the calculation of profit meant as reimbursement for risk and for working capital. These insights can be most clearly developed in a simplified model that abstracts from other issues. Consider the question of how profit should be calculated when it consists solely of reimbursement for assuming the risk of cost variability and for supplying working capital. In particular, assume that there is no facilities capital, that there are no other types of unrecognized costs that must be reimbursed as part of profit, and that there is no reason to pay any economic profit. In this and the next subsection, a conceptually correct rule for calculating profit will be developed and analyzed in a formal model. Then, the actual regulations will be analyzed and interpreted in light of the formal analysis.

A contract is signed in year 0. Then, costs are incurred in years 1 through ℓ and delivery occurs in year ℓ . Assume that costs are incurred at the beginning of each year ℓ . The costs to be incurred during each period are known only randomly at time 0. Let \bar{C}_t be the random cost to be incurred at time t and \bar{C} denote the aggregate random cost.

$$\tilde{C} = \sum_{t=1}^n \tilde{C}_t . \quad (\text{S.3})$$

Let C_t and C denote the realizations of \tilde{C}_t and \tilde{C} . Assume that the delivery date ℓ is known and nonrandom.

The contract is assumed to be of the following form. Let $p(C)$ denote government's promised payment to the firm contingent on the cost outcome C . This is given by

$$p(C) = \pi + E(\tilde{C}) + (1 - \gamma)[C - E(\tilde{C})] . \quad (\text{S.4})$$

As explained above, the constant π is the profit and γ is the firm's share of the risk of cost overruns and underruns. Finally, let α denote the progress payment rate where $\alpha \in [0, 1]$. Government agrees to pay the fraction α of the contractor's costs immediately as they are incurred. These payments will then be deducted from the payment of $p(C)$ at the time of delivery. Formally, a contract can be viewed as a triple (π, γ, α) . The time sequence of events can be summarized as follows.

Year 0: A contract (π, γ, α) is signed. Government and the firm both know the distribution of the random variables

$$\{\tilde{C}_t\}_{t=1}^{\ell} .$$

Year t : The realization of \tilde{C}_t , denoted by C_t , occurs. The firm
 $t = 1, \dots, \ell$ spends C_t dollars. Government immediately gives the firm αC_t dollars.

Year ℓ : The item is delivered. Government pays the firm $p(C) - \alpha C$ dollars.

A classic technique in financial economics is to analyze a relatively complicated financial holding by decomposing it into a set of simpler financial holdings, each of which can be more easily analyzed. This technique can be applied to great advantage in this instance. In particular, we can view the above contract as consisting of two separate contracts. We can calculate profit for the total contract by calculating the profit for each component.

Define a pure production contract (PPC) as one in which the firm bears the risk of cost overruns or underruns but supplies no financing. Formally, this is a contract in which $\alpha = 1$. The sequence of events is as follows.

- Year 0: The contract, $(\pi, \gamma, 1)$, is signed.
 Year t : The realization of \tilde{C}_t , denoted by C_t , occurs.
 $t = 1, \dots, \ell$ However, government pays all production costs.
 Year ℓ : The item is delivered. Government pays the firm

$$\pi + \gamma \left[E(\tilde{C}) - C \right].$$

(If this number is negative the firm pays government money.)

Define a pure financing contract (PFC) as one in which the firm bears no risk of cost overruns or underruns but agrees to supply $(1 - \alpha)$ of the financing. Formally, this is a contract in which $\gamma = 0$. The sequence of events is as follows.

- Year 0: The contract, $(\pi, 0, \alpha)$, is signed.
 Year t : The realization of \tilde{C}_t , denoted by C_t , occurs. The firm
 $t = 1, \dots, \ell$ gives government $(1 - \alpha)C_t$ dollars and government pays all production costs.
 Year ℓ : Government gives the firm $(1 - \alpha)C + \pi$.

Consider any contract (π, γ, α) . Let π_{PPC} and π_{PFC} be any two numbers that sum to π . Then, it is clear that we can view the contract (π, γ, α) as consisting of two separate contracts, a PPC given by $(\pi_{PPC}, \gamma, 1)$ and a PFC given by $(\pi_{PFC}, 0, \alpha)$.

Let $\pi^*(\gamma, \alpha)$ denote the minimum value of π such that the firm will be willing to accept the contract (π, γ, α) . Then, by the above decomposition, we can calculate $\pi^*(\gamma, \alpha)$ as the sum of the required profit on its constituent PPC and PFC components. Formally, let $\pi_{PPC}^*(\gamma, \alpha)$ and $\pi_{PFC}^*(\gamma, \alpha)$ denote the minimum required profit on, respectively, the PPC and PFC contracts. These are defined by

$$\pi_{PPC}^*(\gamma, \alpha) = \pi^*(\gamma, 1) \tag{S.5}$$

and

$$\pi_{\text{PFC}}^*(\gamma, \alpha) = \pi^*(0, \alpha) . \quad (\text{S.6})$$

Then, we can calculate $\pi^*(\gamma, \alpha)$ according to the formula

$$\pi^*(\gamma, \alpha) = \pi_{\text{PPC}}^*(\gamma, \alpha) + \pi_{\text{PFC}}^*(\gamma, \alpha) . \quad (\text{S.7})$$

The required profit on the PPC can be interpreted as payment for bearing contract risk. The required profit on the PFC can be interpreted as payment for supplying working capital.

To develop precise and rigorous characterizations of the nature of the two terms on the right-hand side of Eq. (S.7), we would have to formally model the way that the firm values streams of risky cash flows. This is done in the report by using a commonly accepted valuation model called the capital asset pricing model (CAPM). However, the major qualitative properties of the derived formulas are extremely intuitive and seem likely to be true in a variety of reasonable economic models. The chief virtue of the CAPM is that the formulas all end up being linear, which makes them extremely simple. Furthermore, the simple linear formulas derived through this method bear a relatively close resemblance to the actual formulas used in the regulations. Thus, they provide a natural method of linking the theory to the actual formulas used in practice.

Therefore, we can understand the CAPM as providing a formal basis for creating simple linear formulas that exhibit a number of intuitively reasonable properties. There is no need to actually use the CAPM methodology in this Summary. Rather, the intuitive properties that the profit formulas should exhibit are simply listed and simple linear formulas that display these properties are directly written down.

First, consider the formula for profit on the PPC. This formula should exhibit the following four properties. It should not depend on the progress payment rate, since none of the cash flows do. If the share of risk borne by the firms grows larger, the required profit should probably increase as well. If γ equals 0 and the firm thus bears no risk, then the required profit should probably be zero. If the production costs become "riskier" or more "variable," the required profit should probably increase.

Equation (S.8) is a simple linear formula that captures these properties.

$$\pi_{\text{PPC}}^*(\gamma, \alpha) = \gamma \omega E(\bar{C}) . \quad (\text{S.8})$$

Interpret ω as a measure of the riskiness or variability of production cost where $\omega = 0$ means that production cost is known with certainty and higher values of ω mean that production cost is riskier. Furthermore, interpret ω as the risk per unit of expected cost so that we multiply ω by expected cost to calculate the total risk. Then formula (S.8) states that profit on the PPC equals total risk, $\omega E(\bar{C})$, times the share of total risk actually borne by the firm, γ . This formula exhibits all the properties described above. It adds more structure by additionally assuming that a single parameter can measure the risk of production cost and that the required profit for bearing risk is proportionate to the share of risk borne by the firm.

Now consider the formula for profit on the PFC. This formula should exhibit the following four properties. First, it should not depend on the share of risk, γ , since none of the cash flows do. Second, if the progress payment rate grows larger, then the required profit should decrease because the firm is supplying less financing. Third, if $\alpha = 1$, and the firm supplies no financing, the required profit should probably be zero.

The fourth property concerns how π_{PFC}^* should respond to changes in the risk of production cost. A reasonable initial conjecture might be that π_{PFC}^* should not depend on the risk of production cost, since under the PFC the firm is merely supplying financing and is not responsible for cost overruns or underruns. However, the firm is still exposed to this risk under the PFC, although in a somewhat unusual fashion.

A simple example can best illustrate the nature of this risk. Suppose that a firm's cost of borrowing is 10 percent. Now consider the following contract. The firm is told that immediately after signing the contract a coin will be flipped. Depending on whether the outcome is heads or tails, the firm must loan government either \$100 or \$200. Then, one year later the firm will receive back exactly the amount loaned plus a fixed fee π . The fee π is agreed to in advance and is the same whether \$100 or \$200 is loaned. What value of π would the firm require? Its expected borrowing cost is \$15. However, the contract is risky for the firm and it might require a fee greater than \$15 if it were adverse to bearing this risk.

This example captures precisely the situation that occurs under the PFC. The firm is not sure how much it will be required to loan the government because production costs are uncertain. However, the

profit or fee for providing this loan is fixed and does not vary with the amount actually loaned. Thus, production cost risk does affect the required profit on the PFC. In particular, the required profit should rise as production cost grows riskier.

A simple linear formula that captures these properties will now be developed. Let R_F denote the rate of return that the firm would require on a risk-free investment. Then let F denote the amount of profit that the firm would have to be paid to agree to finance all of the expenditures if it were risk-neutral (or equivalently, if all production costs were equal to their expectations with certainty). It is defined by

$$F = \sum_{t=1}^T E(\bar{C}_t) \left\{ (1 + R_F)^{+1-t} - 1 \right\} . \quad (S.9)$$

The desired formula is given by Eq. (S.10).

$$\pi_{PFC}^*(\gamma, \alpha) = (1 - \alpha)(1 + \omega)F . \quad (S.10)$$

Formula (S.10) says that the cost of supplying 100 percent of the financing is $(1 + \omega)$ times the risk-neutral financing cost, where ω is the same measure of risk used in Eq. (S.8). This is intuitively reasonable since the source of the risk is the same, namely, production cost risk. Formula (S.10) also says that the required profit is proportionate to the share of financing actually supplied by the firm, $(1 - \alpha)$.

Combining Eqs. (S.8) and (S.10) yields the following formula.

$$\pi^*(\gamma, \alpha) = \gamma \omega E(\bar{C}) + (1 + \omega)(1 - \alpha)F . \quad (S.11)$$

The first term is payment for the risk of cost overruns and underruns assumed by the firm. The second term is payment for the contract financing supplied by the firm.

A formula of exactly this form can be derived with the CAPM. In the CAPM the risk parameter, ω , has a very precise interpretation, which may be somewhat surprising to readers unfamiliar with it. Namely, ω is the negative of the covariance of production costs with the stock market as a whole. The reason for this is that the fundamental modeling assumption of the CAPM is that the investor-owners of the firm own an extremely well-diversified portfolio and thus care only about risk that cannot be diversified. It is important to note that if the CAPM is correct and firms do not need to be reimbursed for bearing

diversifiable risk, this would have profound implications for the pricing of defense contracts. This is because it seems likely that much of the risk associated with defense production is of a technical or scientific nature and is thus completely uncorrelated with movements of other asset prices. The CAPM states that firms need not be reimbursed for assuming these risks.

Whether or not the risk measure, ω , ought to include all risk or only nondiversifiable risk is an interesting question raised by the CAPM. However, the validity of formula (S.10) is basically an entirely independent question. Exactly the same formula can be derived by assuming that the firm uses a utility function to value cash flows that is linear in mean and standard deviation. In this case, ω is interpreted as the standard deviation of production cost and thus includes all risk, not merely nondiversifiable risk. Other interpretations are possible as well. For example, it may be that contracting officers normally think of target cost as the most likely cost if nothing goes wrong. In this case, the target cost will be less than the expected cost. It is straightforward to show that this theory generates formula (S.11) if the firm is risk-neutral.

THE IRR

The analysis above sheds light on the question of whether the internal rate of return (IRR) provides a useful way to evaluate profit rules. The IRR for any investment project is defined to be the interest rate that causes the project to have a net present value of 0; i.e., it is the rate of return that the project earns. Suppose that the firm requires a profit of π_{PPC}^* and π_{PFC}^* on the two component contracts. Then the IRR is the solution to the following equation.

$$-\sum_{t=1}^{\ell} \frac{(1-\alpha)E(\tilde{C}_t)}{(1+IRR)^t} + \frac{\pi_{PPC}^* + \pi_{PFC}^* + (1-\alpha)E(\tilde{C})}{(1+IRR)^{\ell}} = 0 \quad (S.12)$$

The firm expects to invest the amount

$$(1-\alpha)E(\tilde{C}_t)$$

in each period

$$t \in \{1, \dots, \ell\}.$$

Then it expects to receive the amount it invested,

$$(1 - \alpha)E(\tilde{C}) ,$$

plus a profit, $\pi_{PPC}^* + \pi_{PFC}^*$, in period ℓ . Thus, intuitively, we can think of the IRR as calculating profit as a percentage return on the firm's up-front investment. Mathematically, there is no problem with performing this calculation. Conceptually, however, the calculation may not be of much value, because profit is a return for two things—bearing risk and supplying up-front investment. Since part of the required profit is unrelated to up-front investment, calculating profit as a percentage return on up-front investment is not necessarily a meaningful or useful calculation.

In particular, if we calculate the IRR yielded by a correctly priced contract and then calculate how the IRR changes as various contracting parameters change, we are likely to observe some seemingly bizarre and counterintuitive behavior. But this does not mean that the pricing rule is incorrect. It means that the IRR measure is not a particularly useful way of thinking about the problem.

Two examples may help explain this point. Both examples illustrate the same basic idea. Namely, if we change a contract to reduce the required up-front investment but leave the amount of risk the firm is exposed to unchanged, then the IRR from the correct profit rule should increase. The explanation is that since the risk is unchanged, profit paid as reimbursement for risk will not change. This in turn implies that profit calculated as a return to up-front investment will increase.

The first example is the most transparent. Suppose that the progress payment rate increases. This reduces the firm's up-front investment. However, it does not affect the amount of risk the firm bears on the PPC and thus π_{PPC}^* is unchanged. This implies that the IRR should increase as the progress payment rate increases. In fact, if the firm receives 100 percent progress payments, a correctly priced contract will exhibit an infinite IRR.

The second example concerns contract length. Consider the somewhat artificial thought experiment of holding total expected cost and the uncertainty of cost constant while decreasing the length of the contract. In such a case, the firm would have to supply working capital for a shorter length of time. Thus, there is a sense in which the "amount" of required investment has shrunk. Therefore, by the same reasoning as above, the IRR on a correctly priced contract should rise.

That is, holding everything else constant, shorter contracts should exhibit higher IRRs.

The second example is more complicated than the first because, unlike the progress payment rate, contract length is not an exogenous parameter. It may generally be true that cost uncertainty grows larger on longer contracts, which might counteract the above effect. For policy purposes the issue boils down to the question of whether the regulations ought to formally specify normal values and allowable ranges for the risk premiums as functions of contract length. Additional empirical research is required to answer this question. However, the more general point of this section is unambiguously true, namely, profit for the PPC is unrelated to the amount of investment that the firm makes in working capital. Thus, measures of profitability that calculate profit as a return on the amount of investment can be misleading and must be interpreted with great care.

APPLICATION OF CONTRACT RISK AND WORKING CAPITAL

It is natural to interpret the technical risk subcomponent of performance profit and the contract risk component as profit for the PPC; similarly, it is natural to interpret the working capital component as profit for the PFC. The nature of the rules used to calculate these components in light of the analysis above will now be considered.

First, consider profit for the PPC. We can view the contract risk profit as being composed of two distinct parts. The "fixed" part consists of the profit that every contract receives. This part has a normal value of 0.5 percent. The "variable" part consists of profit the firm receives only to the extent that it bears the risk of cost overruns and underruns. Note that technical risk profit and the fixed part of contract risk profit do not vary with contract risk. In the notation above, where γ is the cost-sharing parameter, these returns do not depend on γ . In contrast, the variable part of contract risk profit is highly dependent on γ . When $\gamma = 0$, it equals 0. As γ grows, it becomes positive. Finally, if $\gamma = 1$, it is largest. The rule does not specify that variable contract risk profit should grow smoothly with γ . Nevertheless, the current rule for determining profit as a return to risk is clearly roughly of the form

$$\pi = [a + \gamma b]E(\tilde{C}) , \quad (S.13)$$

where $E(\tilde{C})$ denotes expected costs. The parameter a consists of the technical risk profit plus the fixed part of contract risk profit. The parameter b is the variable part of contract risk profit.

Profit regulations correctly identify the fact that two factors determine the risk a firm bears when it signs a contract. The first is the degree of responsibility for cost overruns that the firm assumes. The regulations call this "contract risk." In the model above, this is represented by the parameter γ . The second factor is the uncertainty of cost at the time of contracting. In a state-of-the-art project with many potential technical uncertainties to be resolved, uncertainty will be high. In more standard projects involving well-understood technologies, cost uncertainty will be low. The regulations call this second factor "technical risk." In the model above, this is represented by the parameter ω , which is determined by the uncertainty of costs. Projects with more uncertain costs have a higher value of ω .

The fundamental conceptual error made by the current regulations is the assumption that these two factors are somehow additively separable. That is, the regulations assume that a separate return to each element of risk should be calculated and then these two values should be added together to determine the total return to risk. This is, of course, incorrect. The parameter γ determines the share of the technical risk the contractor is bearing. If γ is 0 (i.e., the firm has a cost plus fixed fee contract), then the firm is bearing none of the technical risk. A zero share of a very large value is still zero. Thus, the return to risk should be zero. The current regulations offer a normal return of 1.7 percent of expected cost and a maximum return of 2.8 percent of expected cost as a return to risk for a contractor that has signed a cost plus fixed fee contract. However, the contractor is actually bearing a zero share of the risk. Therefore his return should also be zero.

The above point is true in any sensible economic model that is used to value risk. In the CAPM model of this report, an even more structured and elegant conclusion is derived, namely, the return to risk the contractor should receive equals the total value of technical risk given by

$$\omega E(\tilde{C})$$

multiplied by (not *added* to) the contractor's share of the risk, γ . This has a strong intuitive justification, since total risk is simply the share of "technical risk" that the contractor assumes.

Thus, the form of the current regulations is clearly incorrect. Even its drafters probably did not intend negotiators to follow it exactly as

written. Doing so would, for example, create the following outcome. In general, contracts with greater technical risk are assigned lower cost-sharing ratios; i.e., if technical risk is higher, γ is lower. Thus, in general, the value of γ is a good measure of the level of technical risk of the project. Contracts with lower values of γ have higher levels of technical risk. Thus, literally following the directions of the regulations would require that negotiators give higher values of technical risk profit to contracts where firms bear the least risk! In particular, the projects with highest cost variability are given cost plus fixed fee contracts. Thus, cost plus fixed fee contracts should in general receive the largest amount of technical risk profit according to the regulations as written. Firm fixed-price contracts should in general receive the lowest amount of technical risk profit according to the regulations as written. This topsy-turvy result is surely not what drafters of the regulations intended.

Now consider profit for working capital. In this summary, only the case of fixed-price contracts that receive progress payments will be considered, since it is the most interesting. From Table S.1, the actual rule is

$$\pi_{\text{PFC}} = (1 - \alpha)R_T L(\ell)E(\tilde{C}) , \quad (\text{S.14})$$

where R_T is the treasury rate. From above, the correct rule is

$$\pi_{\text{PFC}} = (1 + \omega)(1 - \alpha)F , \quad (\text{S.15})$$

where F is the risk-free financing cost calculated using the firm's required return on a risk-free investment, R_F .

To compare the rules in Eqs. (S.14) and (S.15), the procedure is to identify the analogous component in Eq. (S.14) to each of the three components in Eq. (S.15). First, consider the risk premium $(1 + \omega)$. The actual rule obviously contains no risk premium and this should be corrected. The correct rule should instruct the contracting officer to apply the same risk premium to the working capital calculation as he used for the contract risk calculation. Note, however, that this correction will not result in a particularly significant difference given the current values of ω allowed for in the regulations.

Now consider the second component of Eq. (S.15) given by $(1 - \alpha)$. The actual rule also multiplies by $(1 - \alpha)$, so there is no discrepancy.

Finally consider the third component of Eq. (S.15) given by F . The analogue in Eq. (S.13) is the term given by

$$\hat{F} = R_T L(\ell) E(\tilde{C}) . \quad (S.16)$$

Therefore, the existing regulation can be viewed as calculating the risk-free financing cost for a contract by using the formula in Eq. (S.16). The correct value of F is of course defined by

$$F = \sum_{t=1}^{\ell} E(\tilde{C}_t) \left\{ (1 + R_F)^{\ell+1-t} - 1 \right\} . \quad (S.17)$$

The two formulas will clearly be different if R_T is unequal to R_F . Section 7 analyzes the question of whether the treasury rate has been a good measure of the rate of return defense firms would require on a risk-free project and concludes that the treasury rate has perhaps averaged 1.87 percent too low. A new methodology for calculating the treasury rate based on prices in futures markets for interest rates is developed.

Even if $R_T = R_F$, the two formulas are not the same. Note that Eq. (S.16) cannot possibly be perfectly correct because it does not depend on the time pattern of cost incurrence. That is, the profit depends only on contract length and not on whether costs are incurred near the beginning or near the end of the contract. Thus, the best that can be hoped is that Eq. (S.16) is correct for some relatively plausible time pattern of cost incurrence. If it were costly to obtain or process information on the time pattern of cost incurrence, then this might be a rational policy.

However, the supposition of this possible justification is clearly false, for large contracts at least, because contracting officers already estimate cost incurrence in monthly increments for these contracts. Furthermore, it does not appear likely that Eq. (S.16) is the correct formula for a plausible pattern of cost incurrence. This report shows that formula (S.16) is a relatively good approximation to the correct formula when cost incurrence is uniform if a length factor equal to $\ell/2$ is used. The traditional approach of the DoD procurement community has been to assume that $L(\ell) = \ell/2$. This was the approach used by the last major DoD study of profit policy, for example. The current regulations, however, use a different formula for the length factor given by Eq. (S.2). The current regulations probably began with the traditional approach and lowered the

resulting value by 0.35 because it seemed a bit high. This resulted in negative values of $L(\ell)$ for low values of ℓ , so an arbitrary floor of 0.4 was set. A ceiling was also added for good measure. It is unlikely that a great deal of analysis went into empirically estimating a typical pattern of cost incurrence and using it to estimate $L(\ell)$.

Before leaving the issue of working capital, one related issue will be briefly discussed. Because of inaccuracies in the formula for calculating the cost of working capital, defense firms have historically been undercompensated for their working capital costs. This means that increases in the progress payment rate result in increases in defense firms' economic profits. A deeply entrenched mentality within the entire procurement community is that the only policy function served by adjusting the progress payment rate is to adjust defense firms' overall levels of economic profit. Thus, if the defense contractor community perceives that the economic profit level is too low (negative, for example), they will argue that the correct solution is to raise the progress payment rate. Similarly, if a government body perceives that the economic profit level is too high, it will typically argue that a solution would be to lower the progress payment rate.

Under the proposed revision, which correctly calculates the cost of working capital, this will no longer be the case. Changes in the progress payment rate will automatically generate compensating changes in profit paid for working capital costs which (at least in theory) leave firms exactly as well off. Therefore, the proposed revision of profit policy would obliterate what most people currently view as the major policy debate concerning the progress payment rate level. A major point of this report is simply to argue that this is unambiguously an improvement. The overall profit level can (and should be) controlled by simply awarding higher or lower levels of profit. The level of progress payments has a number of important economic effects, independent of the overall profit level. The progress payment rate should be set to strike an optimal balance among these other concerns. To put this another way, the DoD loses a degree of policy freedom by using the progress payment rate to adjust the overall profit level. Furthermore, because all of the debate focuses on this concern about the profit level, the fact that the level of progress payments has other important economic effects is lost sight of.

FACILITIES CAPITAL

The risk considered above might be called *intracontract* risk, since it is risk created when a firm signs a single contract and the risk is fully resolved at the completion of the contract. Facilities capital invest-

ment might involve a certain amount of intracontract risk if the amount of investment required to perform a contract is uncertain at the time the contract is signed. However, the major type of uncertainty involved in facilities capital investment is of a very different sort. This is the risk that the firm accepts by investing in long-lived facilities capital that will outlast any contracts the firm currently has. This type of risk might be called *intercontract* risk.

This report builds a formal model of this type of risk and establishes four extremely intuitive propositions regarding the manner in which profit meant as reimbursement for this type of risk ought to be calculated. First, there is no theoretical reason to expect the return to facilities capital to equal the return to working capital. Second, the risk involved for a particular contract should not necessarily have any bearing on the return allowed for facilities capital. Both of the above propositions simply follow from the fact that intercontract and intracontract risks are distinctly different and are not necessarily equal.

The third proposition is that there is some reason to believe, at least in some cases, that the required return for facilities capital may be substantially larger than the required return for working capital. Although the regulations and this report use the word "risk" to describe why facilities capital must receive a higher return than the risk-free rate, the nature of the calculation is actually somewhat different from that for the case of intracontract risk. For the case of intracontract risk, the essential idea is that a risk-averse firm must receive a premium above its expected production cost. This premium is the return to risk. For the case of facilities capital, the essential idea is that the facility might be unused in the future if no business materializes. Even a risk-neutral firm must be compensated for this contingency. Because the expected future usage rate may be substantially less than 100 percent and because even a risk-neutral firm must be compensated for this risk, it seems plausible that relatively high rates of return might be required on facilities capital in some cases.

The fourth proposition is that capital that is less fungible between commercial and defense uses or that has less resale value bears a higher amount of intercontract risk and thus requires a higher rate of return. Thus, different classes of facilities capital should receive different returns.

The above four propositions suggest four qualitative properties that we might expect a correct rule for facilities capital reimbursement to exhibit. All four features are in fact exhibited by the current policy.

Thus, there is some reason to believe that the current rule is correct, at least in its broad qualitative features.

OTHER UNRECOGNIZED COSTS

There are valid economic reasons to expect various categories of unrecognized costs to exist in addition to the cost of risk-bearing and the cost of capital. Furthermore, passages in the regulations can be interpreted as describing some of these costs. The major problem with the current regulations is that the concept that other unrecognized costs may exist and that reimbursement for them needs to be calculated as part of profit is completely obfuscated by the current format. Vague references to various possible categories of unrecognized costs are scattered throughout the "performance profit" section. However, references to risk are intermixed in an *unorganized* fashion. Furthermore, the performance profit section also describes reasons to actually give economic profit to contracts. All of these discussions are intertwined in a seemingly random fashion and no effort is made to provide any understandable conceptual structure. In particular, the current regulations do nothing to structure policymakers' thinking about profit nor do they provide contracting officers with clear useful guidance to help them understand the nature of and correctly calculate profit.

The solution is to create a separate section of the profit policy regulations entitled "other unrecognized costs." The section would clearly state that its purpose was to identify the magnitude of other unrecognized costs. It would then describe categories of these costs such as misallocation of management effort, opportunity costs of talented employees, and any other categories that policymakers thought were significant. The contracting officer would be instructed to choose a larger (smaller) than average value of profit if these costs seemed larger (smaller) than average for the contract in question.

ECONOMIC PROFIT

Current regulations seem to allow a normal economic profit (i.e., profit in excess of *all* unrecognized costs) of 1.5 percent of expected costs. This is obviously a significant amount and requires justification.

Current regulations explicitly identify three or four situations where the negotiator should award economic profit to give firms an incentive to adopt certain actions. These are relatively trivial cases and the only contribution of this report is to identify them as belonging to the

second category of profit. The major question this raises is whether government could accomplish these same functions by simply requiring firms to adopt these actions as a precondition for doing business with the DoD.

The major contribution of this report regarding the second category of profit is to argue that the function of encouraging innovation is optimally accomplished at least partially through awarding economic profit on contracts. Furthermore, current profit policy rules are performing this function even though it is not explicitly acknowledged. This is important for two reasons.

First, an ongoing and seemingly never-ending debate in policymaking circles in Washington concerns the structure of profit policy regulations. Much of the debate revolves around the question of whether more or less profit should be allowed. The implicit assumption of both sides in this debate often seems to be that all components of profit are of the first category. That is, the only function of profit is to reimburse unrecognized costs. Given this assumption, the debate over whether to raise or lower profits simply becomes a debate over whether the current regulations allow economic profit or not.

Thus, all sides of the debate seem to agree that if one could prove that the current rules generate economic profit, then levels of profit should be adjusted downward.

However, if the contention of this report is correct, then the nature of the debate should be very different. Economic profit on production contracts should simply be viewed as an indirect method of funding innovation. Thus, profit policy must be viewed as a policy instrument controlling the pace of innovative activity. Consequently, an important aspect of the debate over profit policy must be whether the current pace of innovation is adequate and whether it is more appropriate to indirectly fund this innovation through prizes or to directly fund it and why.

Second, it is likely that the need for and importance of innovative activity vary from sector to sector of the defense industry. Therefore, it might be possible to fine-tune the nature of firms' innovative efforts by purposely varying the amount of economic profit offered, depending on the importance of innovation for the type of product being produced.

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1. INTRODUCTION

A. GENERAL

Many items purchased by the Department of Defense (DoD) are one of a kind and involve very advanced and specialized technology. As a consequence, the DoD often finds itself procuring items from a sole source.¹ When competition cannot be used to determine a price for the product, the DoD must instead attempt to determine a fair price for the product based upon the anticipated costs of producing it. In a noncompetitive procurement, the firm must submit extremely detailed estimates of its anticipated costs of production.² DoD negotiators use this information and any other available information to create their own best estimate of the cost of production. A complicated set of regulations, collectively referred to as profit policy, are then used to calculate a "profit" for the contract. The negotiators' estimate of a fair price consists of the anticipated cost plus the "profit." Armed with these calculations, the negotiators then attempt to obtain a price as close to the calculated fair price as possible.

This report provides an economic analysis of the regulations used to calculate the part of the fair price referred to as "profit." It argues that profit actually consists of many conceptually distinct components, each performing a distinct economic function. Furthermore, economic analysis generates a surprising amount of guidance regarding how each component should be calculated to optimally perform its function. The form of the current regulations is optimal in some respects but requires significant revision in others. Thus, this report provides an overall economic framework in which to understand the function of profit in the procurement process. Understanding the function of profit policy is, of course, a necessary precondition to a debate over modifying it.

From an economic perspective the profit awarded on procurement contracts can be divided into two broad categories. First, many economic costs of production are not recognized as costs from the standpoint of government accounting regulations. Thus, reimbursement

¹For example in FY 1984 only 30 percent of DoD procurement dollars were awarded on the basis of price competition (DoD, 1985b).

²By the Truth in Negotiations Act the firm is required to certify, subject to various criminal and civil penalties, that the information submitted is "current, accurate and complete." See Oyer and Mateer (1987).

for these unrecognized costs is called profit. Such costs include the cost of accepting risk when a contract is signed, the cost of working capital, and the cost of facilities capital.

A number of other categories are shown to contain unrecognized costs as well. A separate component of profit must be calculated to reimburse firms for each category of unrecognized costs if one hopes to calculate a price that fully reimburses the firm for all of its costs.

The second category of profit awarded on procurement contracts actually consists of economic profit, i.e., payment of money in excess of the economic costs of performing the contract. The regulations explicitly identify one small subcategory of such profit payments, namely, payment of profit for specific observed actions of the contractor, such as implementing a good socioeconomic program or implementing a more accurate cost-estimating system. However, the regulations do not explicitly acknowledge the most important subcategory of such profit payments—payment of economic profit to provide firms with an incentive to increase their efforts toward innovation. This report argues that profit policy is and necessarily must be structured to provide economic profit on contracts to serve as prizes for innovation.

Therefore, the central theme of this paper is that profit policy regulations should be analyzed in the context of an economic theory that explicitly identifies the economic functions of profit. The most basic distinction is that between profit meant as reimbursement for unrecognized economic costs and economic profit. Within the former category, policymakers need to explicitly identify and analyze the various classes of unrecognized economic costs. Then, the regulations should identify each class of unrecognized cost as a separate component of profit and provide the contracting officer with directions on how to estimate its value. With respect to the latter category, policymakers need to explicitly decide if they wish to use economic profit to create incentives for firms to adopt particular behavior patterns or to exert more effort toward innovation. In particular, they must address the question of whether some method other than awarding economic profit could be used to accomplish the same objective more cheaply. If no cheaper method exists, the manner in which the regulations award profit should be carefully structured to yield the maximum impact on firms' behavior for the minimum cost.

This report lays the foundations for such an economic approach to profit policy regulations by attempting to systematically identify the possible categories of unrecognized costs and incentive schemes that could exist and then employing fairly simple economic theory to explain how to calculate profit in each case. In the case of economic

profit as an incentive scheme, the question of whether these are useful schemes is also addressed. A very close connection to the actual regulations is maintained throughout the entire analysis in two respects. First, the current regulations were read very carefully in an attempt to ferret out all possible unrecognized costs and incentive schemes that the regulations might mention. Second, whenever a particular theoretical component of profit is discussed the relevant portion of the regulations is always identified and a comparison is made between the theoretically correct rule and the actual rule.

This report does not provide a "complete" analysis of the regulations in two respects. First, it ignores a number of issues that may complicate the role of profit policy. These are identified in Subsection D, below. Second, it does not actually state what the correct level of profit should be in all components of the regulations. In particular, the question of how to calculate the correct values for three important parameters is not fully answered. These are the contract risk premium, the facilities capital risk premium, and the innovation incentive.³ However, it is possible to infer the values of these parameters implicitly used in the current regulations. The report concludes in Sec. 14 by presenting a proposed revision of profit policy regulations consistent with the analysis of the preceding sections. The result is a set of regulations that are conceptually clear and straightforward, that have the correct economic form, that have the correct level for the risk-free rate, and that use the levels for the risk premiums and innovation incentive implicit in the current regulations.

This report's major accomplishment is to clarify the economic functions being performed by various components of profit, to suggest a number of important qualitative properties the optimal rules should exhibit, and to infer what levels of profit the current regulations assign to various components. Thus, a very clear and economically rational framework is created for further analysis. This further analysis should attempt to address the question of optimal levels of profit and to consider the implications of relaxing the four assumptions described in Subsection D, below.

B. REIMBURSEMENT FOR UNRECOGNIZED COSTS

The major elements of unrecognized costs are returns to risk-bearing or capital usage. Modern finance theory has developed an elegant

³The most important parameter that this report does determine how to estimate is the risk-free interest rate, described in more detail in Subsection B, below.

theory for precisely calculating the value of these costs—the capital asset pricing model (CAPM). This report uses the framework of the CAPM to develop a conceptually correct rule for estimating these economic costs. The correct rule clearly distinguishes between the concept of intercontract risk, the concept of intracontract risk, the cost of working capital, the cost of facilities capital, and the time value of money and explains how they interact to determine the cost of risk and capital. Because the CAPM generates linear rules, the result is an extremely simple and elegant linear rule for calculating the cost of capital and risk-bearing. Furthermore, the CAPM provides a surprising amount of qualitative guidance as to the structure of each component and the interrelationships between them. This conceptually correct rule is compared with the current regulations. This accomplishes two functions. First, the regulations are often not clear on the purpose of various components of profit that it calculates. Given the insight derived through development of the conceptually correct profit rule, one can often infer what the purpose of various components of profit is meant to be. Second, the correctness of the form of existing rules can be evaluated.

Some of the major conclusions derived through this process are as follows. First, the regulations' calculation of a return for the risk created by signing the contract is confused and conceptually flawed. Risk is viewed as the additive combination of two factors, which is incorrect. Furthermore, some components of profit are labeled as a return to risk although they clearly are not. This report suggests a correct rule that yields the return to risk that the DoD seemed to intend. The normal value of the risk premium of the corrected regulation is 3.7 percent of expected costs. The allowable range is 2.29–5.10 percent of expected costs.

Second, this analysis creates a clear distinction between the concepts of a "risk premium" and the "time value of money." The following example will illustrate this extremely simple but fundamental economic idea. Consider the following gamble. At time 0 a firm receives p dollars. Then it immediately flips a coin. If the coin comes up heads the firm loses \$100. If the coin comes up tails it loses \$300.⁴ How high must p be to induce the firm to accept the gamble? The expected cost is \$200. If the firm were risk-averse it might require a payment higher than \$200. Suppose, for example, that the firm requires a

⁴This gamble can obviously be interpreted as a production contract where the firm receives p dollars and the cost of production is uncertain.

payment of \$250. Then the risk premium can be viewed as 25 percent of expected costs, i.e.,

$$25\% = \frac{250 - 200}{200} \times 100\% . \quad (1.1)$$

Now consider exactly the same gamble, but p is not received until period ℓ , i.e., ℓ years after the coin is flipped and costs are incurred. Now how large must p be? It obviously must be larger to reflect the time value of payment delay. Thus, the payment must be increased by annually compounding it at some interest rate R . That is, the price must now be

$$p = 250(1 + R)^\ell . \quad (1.2)$$

Finally, note that the delay of payment did not affect risk at all. The same payment will simply be received ℓ years later. Thus, the appropriate interest rate is the risk-free rate, i.e., the interest rate that the firm would require on an absolutely risk-free investment.

It will be argued in the report that the risk-free rate for firms has probably averaged around 11 percent or 12 percent over the last 20 years. Therefore, in the above example the firm receives a 25 percent risk premium but the time value of money would probably be calculated by compounding at the rate of 11 or 12 percent. Thus, percentage returns for risk premiums are conceptually distinct and bear no relation to percentage returns for the time value of money.

It will be shown that this simple economic idea plays an important role in correctly calculating profit on defense contracts. On a contract that lasts 5 years, payment will not be received until year 5.⁵ Thus, payment for costs incurred in year 1 is delayed 4 years. However, this is simply a delay and does not affect risk. Therefore, the time value of this delay should be calculated at the risk-free rate. This is true even though the payment may include a much higher percentage risk premium than the risk-free rate.

Third, a method for calculating the risk-free rate is developed, using rates from futures markets for interest rates. The current regulations essentially use an interest rate called the treasury rate as the risk-free rate. It is shown that the treasury rate has perhaps aver-

⁵Of course, some fraction of payment may be received earlier as progress payments. This paragraph refers to the fraction of payment not received until the end of the contract.

aged 1-1/2 percentage points below the value that would have resulted had the correct formula presented in this report been used.

Fourth, two very different types of risk must be considered when calculating profit. The first is labeled *intracontract* risk—the risk a firm accepts by signing a contract. The second is labeled *intercontract* risk—the risk a firm accepts by investing in long-lived facilities capital that will outlast any contracts the firm currently has. It is shown that the return to facilities capital is affected only by *intercontract* risk, whereas working capital investment and the contract risk premium are affected only by *intracontract* risk. This has three major implications for the structure of the rule determining a return to facilities capital. First, there is no theoretical reason to expect the return to facilities capital to equal the return to working capital. Second, the risk involved for a particular contract should have no bearing on the return allowed for facilities capital being used on the contract. Finally, it is straightforward to argue that capital that is less fungible between commercial and defense uses or that has less resale value bears a higher amount of intercontract risk. Thus, different classes of facilities capital should receive different returns. All of these features are exhibited by the current policy. Thus, these features of the current regulation for calculating a return to facilities capital appear to be correct.

Although the above analysis uses the CAPM model, most of the qualitative conclusions tend to hold in other sensible economic formulations as well. The CAPM is used primarily because it seems to be a fairly well-accepted paradigm for valuing risk and capital and because it produces particularly simple linear rules. Thus, simple, easy to interpret, closed-form expressions for calculating profit are derived. Readers unhappy with the CAPM feature that only systematic risk⁶ has a cost could equally well view this analysis as simply assuming that the value of an investment is a linear function of expected value and standard deviation. Readers unhappy with the assumption of linearity or believing that only mean and variance matter could convince themselves that the important conceptual points of this report's analysis depend upon more fundamental economic properties.

C. ECONOMIC PROFIT AS AN INCENTIVE

Current regulations seem to allow a normal economic profit (i.e., profit in excess of *all* unrecognized costs) of 1.5 percent of expected

⁶This concept will be explained in Sec. 3.

costs. This is obviously a significant amount and requires justification.

Current regulations explicitly identify three or four situations where the negotiator should award economic profit to give firms an incentive to adopt certain actions. These are relatively trivial cases and are merely identified here as belonging to the second category of profit. The major question this raises is whether government could accomplish these same functions by simply requiring firms to adopt these actions as a precondition for doing business with the DoD.

Regarding the second category of profit, this report argues that the function of encouraging innovation is optimally accomplished at least partially through awarding economic profit on contracts. Furthermore, current profit policy rules are performing this function even though it is not explicitly acknowledged. This is important for two reasons.

First, an ongoing and seemingly never-ending debate in policymaking circles in Washington concerns the structure of profit policy regulations. Much of the debate revolves around the question of whether more or less profit should be allowed. The implicit assumption of both sides in this debate often seems to be that all components of profit are of the first category. That is, the only function of profit is to reimburse unrecognized costs. Given this assumption, the debate over whether to raise or lower profits simply becomes a debate over whether the current regulations allow economic profit or not. Thus, all sides of the debate seem to agree that if one could prove that the current rules generate economic profit, then levels of profit should be adjusted downward.

However, if the contention of this report is correct, then the nature of the debate should be very different. Economic profit on production contracts should simply be viewed as an indirect method of funding innovation. Thus, profit policy must be viewed as a policy instrument controlling the pace of innovative activity. Consequently, an important aspect of the debate over profit policy must be whether the current pace of innovation is adequate and whether it is more appropriate to indirectly fund this innovation through prizes or to directly fund it and why.

Second, it is likely that the need for and importance of innovative activity varies from sector to sector of the defense industry. Therefore, it might be possible to fine-tune the nature of firms' innovative efforts by purposely varying the amount of economic profit offered depending

on the importance of innovation for the type of product being produced.

D. LIMITING ASSUMPTIONS

Because a complete theory is beyond the scope of this report, four assumptions are made so that certain issues that complicate the role of profit policy can be ignored. First, it is assumed that government receives "current accurate and complete" information from the firm, i.e., on the day of contracting government and the firm are equally well informed about the possible costs of production. Thus, the issue of whether profit policy should be altered to attempt to induce truthful revelation of information need not be considered. Second, it is assumed that the fair price calculated by the negotiator is actually the final negotiated price as well. Thus, the issue of whether profit policy should be altered to attempt to compensate for the effects of negotiations need not be considered. Third, it is assumed that the firm will attempt in good faith to minimize its costs of producing the good when it chooses a production technology. Thus, the issue of whether profit policy should be altered to attempt to give firms the incentive to minimize costs of production need not be considered. Finally, it is assumed that all costs of production are direct costs and are correctly assigned to each contract. Thus, the complex question of how to optimally allocate joint costs across contracts need not be considered.⁷

Because these are all important issues, they have been explicitly listed. However, economic analysis often proceeds most fruitfully by developing a very thorough and complete understanding of a fairly simple "base case." Then, the effects of particular complications can be analyzed as departures from this thoroughly understood case. This report develops an analysis for such a base case. A number of important roles for profit policy remain in the base case model and a very rich theory of the manner in which regulations can optimally implement these roles is developed.

E. RELATED WORK

Much of the existing literature on profit policy consists of DoD and Government Accounting Office (GAO) studies that simply attempt to empirically estimate the return on investment earned by defense firms. (See DoD (1985a) for the most recent DoD study and further

⁷See Rogerson (1991b) for a discussion of the incentive effects of cost-allocation procedures.

references.) Osband (1992) makes a very interesting contribution to this literature by calculating the theoretical internal rates of return that current and past versions of profit policy generate. This report relies on my previous work (Rogerson, 1989, 1991a), which develops the theory that economic profit serves as a prize for innovation. See Lichtenberg (1988a, 1988b) for related empirical studies.

F. ORGANIZATION OF THE REPORT

Section 2 provides a brief overview of current profit policy regulations and Sec. 3 introduces the CAPM model. Then, Sec. 4 presents the major theoretical model of the report, which calculates the value of a single contract to the firm. Since facilities capital outlasts a single contract, the issue of facilities capital cannot be addressed in this model. Thus, it is assumed that no facilities capital is used. For simplicity it is also assumed that no unrecognized costs exist other than the cost of risk-bearing and working capital. Sections 5–9 then apply the model of Sec. 4 to analyze the relevant components of profit policy. Section 10 investigates the nature of other unrecognized costs (i.e., unrecognized costs other than risk-bearing, working capital, or facilities capital). It shows that many categories of such costs exist and how the rule of Sec. 4 should be altered to incorporate them. Section 11 generalizes the model to allow facilities capital. Then, Secs. 12 and 13 consider the question of profit meant as economic profit. Finally, Sec. 14 summarizes many of the report's conclusions by presenting a proposed revision of profit policy regulations consistent with the analysis of the preceding sections.

2. CURRENT PROFIT POLICY

A. THE REGULATORY CONCEPTION OF PROFIT

DoD procurement regulations essentially use the term "cost" in the same fashion as accountants do. Cost consists of operating cost plus depreciation of physical capital. Payments to the contractor in excess of anticipated operating costs and depreciation are thus viewed as profit. Because government must reimburse firms for use of their capital and risk-bearing (among other things), profit will generally be positive.

Profit policy regulations instruct the contracting officer on how to determine a correct level for *ex ante* or expected profit for a contract. This can be formalized as follows. Let \tilde{C} denote the (random) cost that a contractor will incur on a contract. Let C denote the realization of \tilde{C} and $E(\cdot)$ denote the expectation operator. A contract includes some function $p(C)$, which describes the price government will pay the firm depending on the level of costs incurred. *Ex post*, the contractor's profit will be

$$p(C) - C. \quad (2.1)$$

Therefore, the contractor's *ex ante* or expected profit is equal to

$$\pi = E(p(\tilde{C})) - E(\tilde{C}). \quad (2.2)$$

Profit policy regulations address themselves to the question of how large a value for Eq. (2.2) should be allowed.

DoD contracts are typically linear. The contract is usually written and thought of in a form such that the level of expected profits is apparent. In particular, if $p(C)$ is a linear function of C , it can always be written in the form

$$p(C) = E(\tilde{C}) + \pi + (1 - \gamma)[C - E(\tilde{C})], \quad (2.3)$$

where π and γ are constants. The parameter π is the level of expected profit offered by $p(C)$. Thus, π will typically be a positive number.

The parameter γ is always chosen between 0 and 1 for DoD contracts. It is the share of cost overruns and underruns borne by the contractor. When $\gamma = 0$ the contractor bears none of a cost overrun or underrun. When $\gamma = 1$ the contractor bears 100 percent of a cost overrun or underrun.

Since profit policy regulations are focused solely on expected profit, the term "profit" will always be used to mean "expected profit" in this report.

B. FIXED-PRICE-TYPE COMPARED WITH COST-TYPE CONTRACTS

Every contract signed by the DoD is formally classified as a cost-type or a fixed-price-type contract and economists often have a confused understanding of the distinction between them. The important point is that the cost-sharing ratio does not necessarily have any connection to the type of the contract. A contract will include a payment rule of the form of Eq. (2.3). However, it will also include a statement that labels it as being either a cost-type or fixed-price-type contract. In a fixed-price-type contract, γ can be equal to any value in $[0, 1]$. The same is true for a cost-type contract. A fixed-price-type contract with $\gamma = 1$ is called a firm fixed price (FFP) contract. Other fixed-price-type contracts are called fixed price incentive (FPI) contracts. A cost-type contract with $\gamma = 0$ is called a cost plus fixed fee (CPFF) contract. A cost-type contract with other values of γ is called a cost plus incentive fee (CPIF) contract.

There are two major differences between a cost-type and a fixed-price-type contract.

First, the DoD pays progress payments differently on cost-type contracts. (This is discussed in Subsection E, below.)

Second, in real contracts the payment function is not actually linear over the entire real line. In particular, contracts typically specify some maximum cost value (often 120 percent to 140 percent above expected costs) at which the payment function changes form. The nature of the changed form is different for cost-type and fixed-price-type contracts. For cost-type contracts, government bears 100 percent of cost increases above the specified maximum. For fixed-price-type contracts, the firm bears 100 percent of cost increases above the specified maximum. That is, CPIF contracts revert to CPFF for high enough costs; FPIF contracts revert to FFP for high enough costs.

Finally, note that, in practice, cost-type contracts usually have lower values of γ than do fixed-price-type contracts. Thus, in practice, fixed-price-type contracts are used where the contractor is to bear substantial amounts of risk. In the current procurement environment, fixed-price-type contracts are used for the bulk of manufacturing and production contracts, whereas cost-type contracts are used for most R&D contracts.

C. THE *FAR* AND *DFAR*

Before 1984 the various branches of the federal government each had separate sets of regulations governing their procurement processes. In 1984 the *Federal Acquisition Regulations (FAR)* was published as a general set of regulations governing the procurement process of all government agencies. These are published as Title 48 of the *Code of Federal Regulations*, Chapter 1. Each government agency also publishes a supplementary set of regulations that are consistent with the *FAR* but describe in more detail aspects of procurement of particular interest to that agency. The DoD supplement is called the *Defense Federal Acquisition Regulations (DFAR)* and is published as Chapter 2 of Title 48 of the *Code of Federal Regulations*. The general regulations contained in the *FAR* are very detailed and a very large fraction of the DoD's procurement process is governed by the *FAR*. A typical reference would be: 48 CFR 115.243-1. This indicates (from left to right) that the reference is

- (i) Title 48 of the *Code of Federal Regulations*,
- (ii) Chapter 1 (thus, this is a reference to the *FAR*. A reference to the *DFAR* would have a 2 in this spot denoting Chapter 2),
- (iii) Part 15,
- (iv) Subpart 2,
- (v) Section 43,
- (vi) Subsection 1.

Further subdivisions also exist. Thus, additional numbers to the right indicate further subdivisions.

D. PROGRESS PAYMENTS¹

Progress payments are payments to the contractor to reimburse it for costs incurred before actual delivery of the finished product. Progress payments affect profit policy in that without them the contractor must supply its own working capital. This in turn means that the contractor must be reimbursed for its cost of working capital. This reimbursement is part of profit.

A contract for a major military item such as an airplane will typically take three years to complete.² Thus, working capital used on a contract would roughly amount to 1.5 times operating cost.³ The net book value of physical capital used on a typical military contract is closer to 0.1 times operating cost. Thus, the level of progress payments supplied can have a large effect on the overall capital requirements of the firm.

The DoD does in fact provide substantial progress payments on the bulk of contracts it signs. First, consider cost-type contracts. On a cost-type contract, 100 percent progress payments are supplied. Furthermore, progress payments are paid on profit as well as costs. For example, suppose a firm spends x in a period, total expected costs for the project are $E(\tilde{C})$, and profit is π . Then government will immediately give the firm

$$x + \frac{x}{E(\tilde{C})} \pi \quad (2.4)$$

dollars. That is, the firm receives its costs plus a proportionate share of the profit.

¹See DoD (1985a) for more complete discussions of progress payments and their history.

²DoD (1985a), p. IV-15.

³Suppose that a contract will cost C dollars to produce and take t years. Appendix D shows that a firm that incurred costs at a uniform rate of C/t dollars per year for t years would have working capital costs of approximately

$$\frac{RCt}{2},$$

where R is the interest rate. Thus, the firm could be thought to have an "average" level of working capital of

$$\frac{Ct}{2}.$$

For a three-year contract, this value is $1.5C$.

Very short or small fixed-price-type contracts do not receive progress payments. However, measured in dollar value, the vast majority of fixed-price-type contracts receive progress payments. On fixed-price-type contracts the customary progress payment rate for most firms is 80 percent; small businesses receive 85 percent. However, these payments are based only on costs, not on profit. Thus, in the same situation as described above, a normal firm performing on a fixed-price-type contract would receive

$$0.80x \quad (2.5)$$

The regulations also allow firms with large fixed-price-type contracts to submit detailed projections of the time pattern of expected cost incurrence together with projections of payment lags and floats. These data are used to calculate an individualized progress payment rate for that contract through use of a computer program called CASH IV. The stated intent of the program is to calculate a progress payment rate that has the firm bear 20 percent of its financing costs when the effects of lags and floats and the particular time pattern of cost incurrence is considered. The rate calculated under this program is called a flexible progress payment rate.⁴

Although progress payments are substantial, they are not 100 percent for fixed-price-type contracts. The majority of manufacturing and production contracts are fixed-price-type contracts. Thus, fairly substantial amounts of contractor-supplied working capital are required on a typical production contract. With 80 percent progress payments, the typical three-year contract might require roughly 0.3 times its operating cost in working capital.⁵ This is still three times as large as typical physical capital usage. Thus, the issue of how to reimburse contractors for working capital usage is important.

The symbol α will be used to denote the progress payment rate. It will be more convenient to express the progress payment rate as a fraction than as a percentage in formulas. Thus, α will be a number between 0 and 1; i.e., the normal progress payment rate of 80 percent corresponds to a value for α of 0.80.

⁴For any contract, a given fixed rate is calculated and used through the life of the contract. The rate is called "flexible" because it may be set at a value other than 80 percent.

⁵This uses the same approximation as above.

E. THE TREASURY RATE

DoD regulations often use an interest rate called the treasury rate to calculate profits that are a return to capital. The treasury rate is an interest rate published semiannually (once in December to apply to next January through June and once in June to apply to next July through December) in the *Federal Register* by the Treasury Department. The Treasury Department was directed to publish this rate by Public Law 92-41, passed on July 1, 1971. The legislation gave the following rather vague directions for determining this rate.

Such a rate shall be determined by the Secretary of the Treasury, taking into consideration current private commercial rates of interest for new loans maturing in approximately five years.

The legislation is obviously too vague to allow prediction of how high the interest rate will be in relation to other common interest rates. I directly contacted the treasury officials responsible for setting this rate and was told that no specific formula exists for calculating it. Rather, the Treasury Department takes its legislative direction at face value and attempts to estimate what commercial firms pay for five-year loans at the time the new rate is being set. Unfortunately, there are not always large numbers of five-year bond issues or loans to observe. Thus, the officials also look at a variety of other interest rates and their trends. Once again, the above description is too vague to adequately predict the size of the rate.

Therefore, the only method for determining the relative size of the treasury rate seems to be to actually compare the historical values of the treasury rate to various other interest rates. These data are presented in Table 2.1. The values of the treasury rate since its inception in 1971 are presented. Then time series for three other interest rates are also presented. The first rate is the interest rate on short-term (one-month) treasury bills. The second rate is the interest rate being offered on government bonds with five-year maturities. This is a useful rate to consider because it could be viewed as a five-year rate with no default risk. Since the legislation creating the treasury rate suggests that five-year loans be considered, it seems reasonable to conjecture that the treasury rate should vary particularly closely with this rate, because expectations over the term structure of interest rates and inflation should affect commercial five-year loans and government five-year loans in approximately the same fashion. Thus, the treasury rate should be equal to the five-year default-free rate plus a default premium. Finally, the prime rate is considered. This is included, since it is commonly cited.

Table 2.1
The Treasury Rate and Other Interest Rates
(in percent)

Date	Treasury Rate ^a	One-Month Treasury Bill Rate ^b	Intermediate-Term Government Bonds ^c	Prime Rate ^d
1971 July	7.375	4.91	6.63	5.83
1972 January	6.750	3.54	5.56	5.06
1972 July	6.875	3.78	5.95	5.25
1973 January	7.125	5.41	6.41	6.00
1973 July	7.750	7.96	7.76	8.29
1974 January	7.875	7.83	6.87	9.67
1974 July	9.125	8.73	8.38	11.94
1975 January	8.875	7.19	7.30	10.05
1975 July	8.875	5.92	7.82	7.15
1976 January	8.750	5.79	7.43	7.00
1976 July	8.500	5.79	7.32	7.25
1977 January	7.750	4.41	6.73	6.25
1977 July	7.875	5.16	6.75	6.75
1978 January	8.250	6.04	7.73	7.93
1978 July	9.000	6.93	8.36	9.00
1979 January	9.875	9.64	8.95	11.75
1979 July	10.250	9.64	8.87	11.54
1980 January	12.125	10.03	10.93	15.25
1980 July	10.500	6.55	9.96	11.48
1981 January	14.625	13.22	12.75	20.16
1981 July	14.875	15.94	15.33	20.39
1982 January	14.750	10.03	13.97	15.75
1982 July	15.500	13.35	13.15	16.26
1983 January	11.250	8.60	10.57	11.16
1983 July	11.500	9.25	11.68	10.50
1984 January	12.375	9.51	11.37	11.00
1984 July	14.375	10.30	12.74	13.00
1985 January	12.125	8.09	10.81	10.61
1985 July	10.375	7.70	10.02	9.50
1986 January	9.750	6.93	8.70	9.50
1986 July	8.500	6.42	7.28	8.16
1987 January	7.625	5.16	6.85	7.50
1987 July	8.875	5.66	8.17	8.25

^aThis is the treasury rate as published in the *Federal Register* for each six-month period beginning in January or July. This time series was compiled by Commerce Clearing House Inc. (1988).

^bThis is the yield (i.e., imputed interest rate) on U.S. treasury bills having a maturity of one month. The yields reported are for the months of July or January in the various years. See Ibbotson (1988), p. 41, for a more detailed explanation.

^cThis is the yield (i.e., imputed interest rate) on U.S. government bonds with a maturity of five years. The yields reported are for July or January in the various years. See Ibbotson (1988), p. 39, for a more detailed explanation.

^dThis is the prime rate charged by commercial banks during January and July for the various years as reported in various issues of the *Federal Reserve Bulletin* published by the Board of Governors of the Federal Reserve System.

Figures 2.1 to 2.3 display the behavior of the treasury rate relative to the three other rates. Table 2.2 reports the average difference between the treasury rate and the three other rates. Finally, Table 2.3 reports the results of regressing the treasury rate on the three rates.

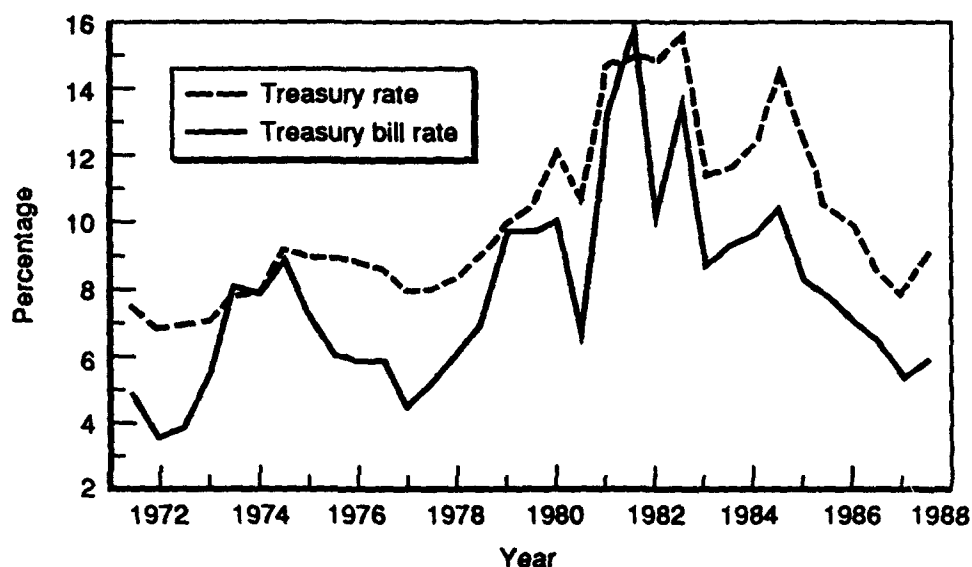


Fig. 2.1—The Treasury Rate Compared with the Treasury Bill Rate

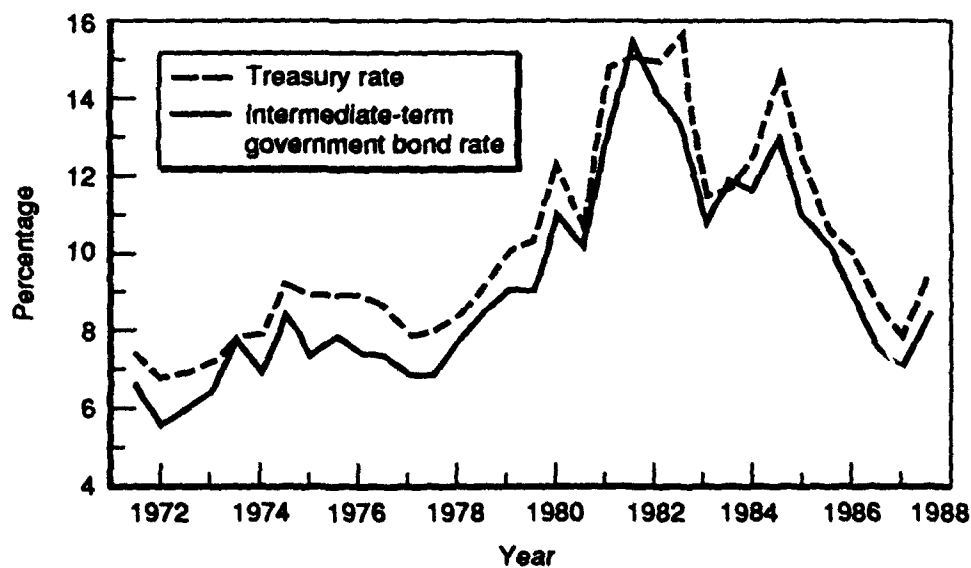


Fig. 2.2—The Treasury Rate Compared with the Rate on Intermediate-Term Government Bonds

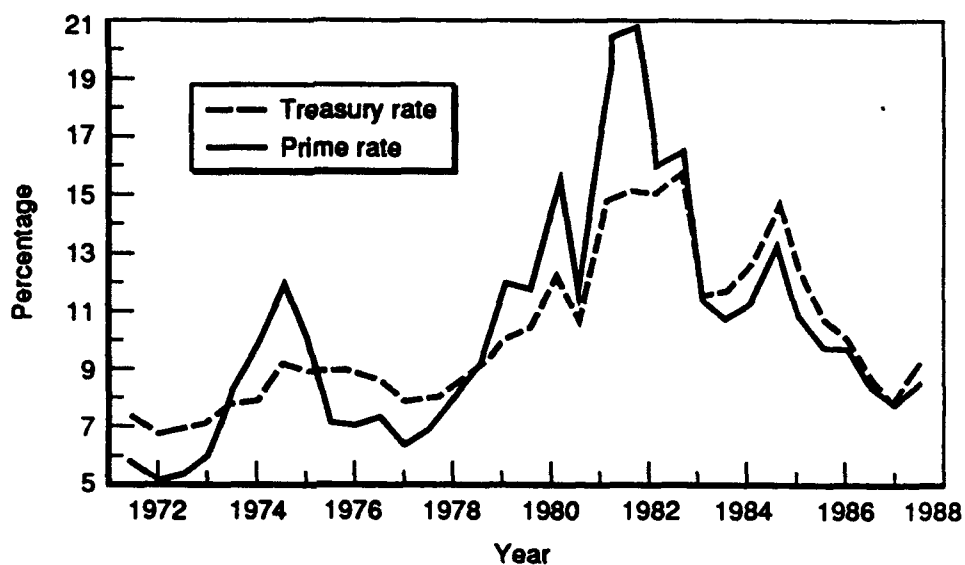


Fig. 2.3—The Treasury Rate Compared with the Prime Rate

Table 2.2

**Average Values of the Treasury Rate and Other Interest Rates
(in percent)**

Rate	Average Value	Treasury Rate Average Value Minus Average Value
Treasury	10.00	0
One-month treasury bills	7.74	2.26
Intermediate-term government bonds	9.06	0.94
Prime	10.16	-0.16

Table 2.3

**Results of Regressing the Treasury Rate on Other Interest Rates
(in percent)**

	One-Month Treasury Bills	Intermediate-Term Government Bonds	Prime
Intercept	3.76	1.00	3.96
Slope	0.81	0.99	0.59
R ²	0.78	0.95	0.81

First, observe Table 2.2. This shows that the treasury rate has averaged 2.26 points above the treasury bill rate, 0.94 points above the intermediate-term government bond rate, and 0.16 points below the prime. Thus, its average value has been approximately equal to the prime. Now observe Figs 2.1–2.3. The treasury rate approximately tracks all three time series. There appears to be a tendency for the treasury rate to not rise as fast as the treasury bill rate and prime rate during periods of high interest rates. Now observe Table 2.3, which summarizes the regression results. It is clearly the case that the treasury rate is most highly correlated with the intermediate-term government bond rate. The treasury rate moves up and down with the bond rate (i.e., the slope is 1) but remains approximately 1 point above it (i.e., the intercept is 1). As the graphs suggest, the treasury rate is not quite so highly correlated with the other two rates.

In conclusion, then, it appears that the treasury rate is almost perfectly predicted by adding 1 percent to the yield on government bonds with five-year maturities. It is not quite as highly correlated with the treasury bill rate or prime rate. In particular, it does not rise as fast as these rates during periods of high interest. It has averaged about 2-1/4 points above the treasury bill rate and has approximately been equal to the prime rate over the past 16 years.

F. CALCULATION OF PROFIT

The current regulations used to calculate profit, described below (with one exception, which will be mentioned), are collectively referred to as the “weighted guidelines” and are contained in the *DFAR*.⁶ These regulations were initially created in 1964 and underwent major revisions in 1976, 1980, and 1987.⁷

Tables 2.4 and 2.5 summarize the current regulations. As can be seen from the tables, profit is broken into four components. Many of the components are further broken down into subcomponents. The method for calculating profit for a given component or subcomponent is always the same. The regulations specify a “base” for the profit calculation. This may be, for example, total expected cost or the net book value of facilities capital, depending on the component. Then, the contracting officer calculates profit by selecting a percentage to apply to the base. The regulations always specify a normal value for

⁶48 CFR 215.9.

⁷See DoD (1985a) and Osband (1992) for a history of the regulations.

Table 2.4
Current Profit Policy When Base Cost Equals Expected
Cost Minus G&A

Profit Component	Normal Value, %	Allowable Range, %	Base That % Is Applied To
Performance risk			
Technical risk ^a	1.2	0.6 to 1.8	$E(\tilde{C})$ minus G&A
Management ^a	1.2	0.6 to 1.8	$E(\tilde{C})$ minus G&A
Cost control ^a	1.6	0.8 to 2.4	$E(\tilde{C})$ minus G&A
Total ^a	4	2 to 6	$E(\tilde{C})$ minus G&A
Contract risk			
FFP ^a	3	2 to 4	$E(\tilde{C})$ minus G&A
FPI or CPI ^a	1	0 to 2	$E(\tilde{C})$ minus G&A
CPFF ^a	0.5	0 to 1	$E(\tilde{C})$ minus G&A
Facilities capital			
Profit received by all contracts	Treasury rate	Treasury rate	K
Standard extra profit			
Land	0	0	K_L
Buildings	15	10 to 20	K_B
Equipment	35	20 to 50	K_E
Alternative extra profit ^a	2	2	$E(\tilde{C})$ minus G&A
Working capital			
Cost-type contracts	0	0	—
Fixed-price contracts with no progress payments	2	2	$E(\tilde{C})$ minus G&A
Fixed-price contracts with progress payments	Treasury rate	Treasury rate	$L(f)(1 - \alpha)E(\tilde{C})$

^aThese are the items that change between Tables 2.4 and 2.5.

the percentage and an allowable range. Then, a variety of factors that should affect how large a value the contracting officer should choose from the allowable range are listed and discussed.

There are two tables summarizing the regulations because many of the components use a base equal to "expected cost minus general and administrative (G&A) costs." G&A essentially consists of central management costs. Historically, G&A expense has averaged approximately 12 percent of total cost including G&A.⁸ There may be some reasons related to incentives for cost minimization in the presence

⁸Meyers et al. (1985), p. 2-9.

Table 2.5
Current Profit Policy When Base Cost Equals Expected Cost
Including G&A

Profit Component	Normal Value, %	Allowable Range, %	Base That % Is Applied To
Performance risk			
Technical risk ^a	1.06	.53 to 1.58	$E(\bar{C})$
Management ^a	1.06	.53 to 1.58	$E(\bar{C})$
Cost control ^a	1.40	.70 to 2.11	$E(\bar{C})$
Total ^a	3.52	1.76 to 5.28	$E(\bar{C})$
Contract risk			
FFP ^a	2.64	1.76 to 3.52	$E(\bar{C})$
FPI or CPI ^a	.88	0 to 1.76	$E(\bar{C})$
CPFF ^a	.44	0 to 0.88	$E(\bar{C})$
Facilities capital			
Profit received by all contracts	Treasury rate	Treasury rate	ℓK
Standard extra profit			
Land	0	0	ℓK_L
Buildings	15	10 to 20	ℓK_B
Equipment	35	20 to 50	ℓK_E
Alternative extra profit ^a	2	2	$E(\bar{C})$
Working capital			
Cost-type contracts	0	0	—
Fixed-price contracts with no progress payments	2	2	$E(\bar{C})$
Fixed-price contracts with progress payments	Treasury rate	Treasury rate	$L(\ell)(1 - \alpha)E(\bar{C})$

^aThese are the items that change between Tables 2.4 and 2.5.

of joint costs to exclude G&A from the profit calculation. Given that this report does not explore these issues, the only effect for this report's purposes is algebraic. The percentages described in the regulations can be converted to percentages of total cost including G&A by multiplying by 0.88. Table 2.4 presents the rules as they are actually described in the regulations. The percentages of expected cost minus G&A in Table 2.4 are simply multiplied by 0.88 to convert them to percentages of expected cost. These are presented in Table 2.5.

It will be notationally much less cumbersome to analyze models where the extra term of G&A does not have to be subtracted for some fraction of the calculations. Therefore, all of the analysis in this report will speak of percentages of expected cost instead of expected cost

minus G&A. This is why Table 2.5 is presented. However, it should be stressed that this is simply a choice of language, not of substance. Any percentage of expected cost can always be converted back into a percentage of expected cost minus G&A by multiplying by 1.14.

The four components of profit will now each be described in more detail. The reader should refer to Tables 2.4 and 2.5 when reading these descriptions.

1. Performance Profit

This section of the regulations is actually entitled "performance *risk*." However, this term is a misnomer, since the profit is broken into three subcomponents and only one of these involves risk. Therefore, it will be called "performance *profit*" in this report to minimize confusion.

The names of the three subcomponents and their normal and allowable ranges are presented in Tables 2.4 and 2.5. The regulations use a base of expected cost minus G&A. These percentages are presented in Table 2.4. Translations to percentages of expected cost are presented in Table 2.5.

From reading the descriptions in the regulations of factors that should cause the contracting officer to choose a high or low value for each subcomponent, one can attempt to infer the nature of profit that each subcomponent is attempting to calculate. The technical risk component is clearly meant to reimburse the firm for bearing risk, since the value awarded is supposed to increase as the uncertainty of project costs increases. However, no simple conclusions are possible about the other two subcomponents. The descriptions contain a hodgepodge of factors that do not immediately suggest any particular theory of profit. A major task of this report will be to attempt to make economic sense out of the variety of factors listed under these two subcomponents.

2. Contract Risk

All contracts are also given a second profit calculated as a percentage of expected cost minus G&A. Once again, this is described as a return to risk but this time it is labeled a return to "contract risk." The difference between this component and the technical risk component described above is that the contract risk component is meant to respond to the amount of risk-sharing in the contract. Thus, a normal value and allowable range are specified for various types of contracts.

Table 2.4 presents these values as a percentage of expected cost minus G&A as they are presented in the regulations. Table 2.5 translates them into percentages of expected cost. Notice that the normal value and allowable ranges shift upward as the firm bears a greater share of the risk of cost overruns and underruns. In contrast, the technical risk calculation is supposed to be totally independent of the firm's share of the risk.

Whether it makes any sense to distinguish between two risk payments—one that varies with the contractor's share of the risk and one that does not—is considered further in Sec. 6.

3. Facilities Capital

To describe this component some new notation will be useful. Let ℓ denote the length of the contract in years. Let K denote the net book value of all facilities capital. The regulations divide all capital into one of three groups—land, buildings, and equipment. Let K_L , K_B , and K_E denote the net book values of these three categories.

All facilities capital used on a contract receives profit of the treasury rate multiplied by the net book value of the capital for every year the facilities capital is used on the contract. That is, a percentage equal to the treasury rate is applied to a base of ℓK . This component of profit is not part of the weighted guidelines. It appears as a separate item elsewhere and is in the *FAR*, not the *DFAR*.⁹ The reasons for this separation flow from the historical evolution of the policy and the separate statement has no substantive effect.¹⁰

In addition to the treasury rate, the weighted guidelines instruct that an additional return to facilities capital be given. Two different cases are specified and each is considered separately.

The Standard Rule. Except for cases described below, the weighted guidelines instruct that an additional percentage return to the net book value of facilities capital be given for every year the facilities capital is used in the contract. Different returns are allowed for different assets, depending on whether they are land, buildings, or equipment. As usual, a normal value and an allowable range are specified. Tables 2.4 and 2.5 present the normal values and allowable

⁹48 CFR 131.205.10.

¹⁰To confuse matters further, the regulations label this element as a cost. However, it is treated as an element of profit in almost all respects. Therefore it will be called an element of profit in this report. This separation has one very small substantive effect, which will be discussed in Sec. 9.

ranges. Since this rule is expected to be used in most cases it will be called the "standard rule."

The Alternative Rule. Firms that primarily perform research and development or service functions will typically have very small investments in facilities capital. In such cases, the weighted guidelines specify that the negotiator may give the contractor an extra 2 percent of expected cost minus G&A as profit instead of using the rule above. This will be called the "alternative rule." Table 2.4 presents this percentage and Table 2.5 translates it to a percentage of expected cost.

4. Working Capital

The regulations consider three cases.

Case #1: Cost-Type Contracts. Since cost-type contracts receive 100 percent progress payments, no profit as a return to working capital is given to them.

Case #2: Fixed-Price-Type Contracts with no progress payments. In this case a profit equal to 2 percent of expected cost minus G&A is added to the contract. This translates into a profit of 1.76 percent of expected cost including G&A.

Case #3: Fixed-Price-Type Contracts with Progress Payments. In this case a profit equal to

$$R_T(1 - \alpha)L(\ell)E(\tilde{C}) \quad (2.6)$$

is given to the contractor where R_T is the treasury rate¹¹ and $L(\ell)$ is the "length factor." The value of $L(\ell)$ is larger for longer contracts and is given by Table 2.6. Recall that α is the progress payment rate and $E(\tilde{C})$ is the expected cost.

Notice that each time interval in Table 2.6 is six months long. Thus, L increases by 0.25 each half-year or by 0.5 every year. Therefore, for contract lengths between 21 months and 76 months the length factor is simply a discrete approximation of a linear function that increases by 0.5 every half-year. To specify the equation of this linear function we need only specify one point that it passes through in addition to its

¹¹Interest rate will always be expressed in decimal form in the formulas of this report. Thus, for example, if the treasury rate is 10 percent, R_T would equal 0.10.

Table 2.6
The Length Factor

Length of Contract	Length Factor
21 months or less	0.40
22 to 27 months	0.65
28 to 33 months	0.90
34 to 39 months	1.15
40 to 45 months	1.40
46 to 51 months	1.65
52 to 57 months	1.90
58 to 63 months	2.15
64 to 69 months	2.40
70 to 75 months	2.65
76 months or more	2.90

slope. Choose the point (2, 0.65), i.e., for a contract two years long the length factor is 0.65. Then the linear function is

$$L = 0.65 + 0.5(\ell - 2) , \quad (2.7)$$

where ℓ is the length of the contract in years. Rewrite this as

$$L = -0.35 + 0.5\ell . \quad (2.8)$$

Thus, the length factor is essentially given by Eq. (2.8) subject to the constraint that it never be less than 0.4 and never exceed 2.9. This is formally written as Eq. (2.9).

$$L = \begin{cases} 0.4 & , \quad \ell \leq 1.5 \\ -0.35 + 0.5\ell & , \quad 1.5 \leq \ell \leq 6.5 \\ 2.9 & , \quad \ell \geq 6.5 \end{cases} \quad (2.9)$$

The discrete rule and its smooth approximation given by Eq. (2.9) are graphed in Fig. 2.4.

case R refers to the annualized interest rate. (Thus, for example, R_F^t denotes the annualized period t risk-free rate.) If there are m periods per year, the perfectly correct formula for calculating R is given by

$$R = (1 + r)^m - 1 . \quad (3.1)$$

However, this is closely approximated by the formula

$$R = mr , \quad (3.2)$$

which ignores the effects of compounding. For simplicity, formula (3.2) will be used in this report to translate between annualized and per period interest rates.

Proposition 1 presents the basic valuation theorem.

Proposition 1:

Suppose that \tilde{I} is a random income stream received in period t . Then in period $t - 1$ the value of \tilde{I} is given by

$$V_{t-1} = \frac{E(\tilde{I}) - \lambda^t \text{cov}(\tilde{I}, \tilde{r}_M^t)}{1 + r_F^t} . \quad (3.3)$$

This can be equivalently written as

$$V_{t-1} = \frac{E(\tilde{I})}{1 + r^*} , \quad (3.4)$$

where

$$1 + r^* = (1 + r_F) \frac{E(\tilde{I})}{E(\tilde{I}) - \lambda^t \text{cov}(\tilde{I}, \tilde{r}_M^t)} . \quad (3.5)$$

The basic valuation formula can be used to value extremely complicated multiperiod returns by beginning at the last period return and working backward. Thus, the value in period 0 can be calculated for complicated multiperiod returns.

This report makes one more simplifying assumption. It will be assumed that \tilde{r}_M^t is determined by

$$\tilde{r}_M^t = r_F^t + \tilde{\epsilon}_t, \quad (3.6)$$

where $\tilde{\epsilon}_t$ is an i.i.d. random variable (with positive expected value). Thus, the market return relative to the risk-free rate is i.i.d. over time. This means in particular that the parameter λ^t is constant over time. It will therefore simply be denoted by λ .

In applications of the multiperiod CAPM to the capital budgeting problem, it is in fact typical to make an even stronger assumption than Eq. (3.6). It is often assumed that r_F^t is constant *and* that Eq. (3.6) holds. Then the world is i.i.d. through time.³ However, for reasons that will become clear, it was desirable to use a model that allowed the risk-free rate to vary over time. Thus, the slightly weaker assumption that the world is i.i.d. relative to the risk-free rate (as given by Eq. (3.6)) is made.

A number of points will be briefly noted about the valuation formula. First, it yields the value of a random income stream in an optimally diversified portfolio of investments. This results in a number of unusual properties. For example, if all incomes of a random income stream were to double, the value of the stream also exactly doubles. More important, only risk that cannot be diversified affects the value of the income stream. Thus, the value of an income stream is reduced only to the extent that it covaries with the market portfolio. Second, Eq. (3.3) can be viewed as a "certainty equivalent" formula. The value at time t of the random income stream equals its expected value minus an adjustment for risk. This is then discounted at the risk-free rate to yield the value at time $t - 1$. Third, Eq. (3.4) gives the familiar "hurdle rate" formulation. The value of the stream is calculated by discounting the expected return at an interest rate, r^* , greater than the risk-free rate. The rate r^* is often called the hurdle rate. Fourth, the CAPM assumes that investors consider only the mean and variance of their portfolios when calculating an optimal portfolio. This is why only the mean and covariance of \tilde{I} enter the valuation formulas.

Readers unhappy with the property of the CAPM that only systematic risk is priced could replace Eq. (3.3) by the rule

$$V_{t-1} = \frac{E(\tilde{I}) - \lambda \sqrt{\text{var}(\tilde{I})}}{1 + r_F} \quad (3.7)$$

³See, for example, Rubinstein (1973).

and derive many of the same results of this report. That is, one could simply assume that a certainty equivalent in each period is calculated through use of a linear function of mean and standard deviation. Furthermore, most of the major qualitative results of the report seem to depend on fairly fundamental economic principles and do not hinge crucially on the assumptions of linearity or that only mean and variance matter. Therefore, the chief reason for employing the valuation formula (3.3) in the following analysis is simply that it provides a simple closed-form expression for valuing uncertain income streams. This valuation formula has the property that increases in expected return increase value and increases in risk decrease value.

4. THE SINGLE CONTRACT MODEL

A. THE MODEL

A contract is signed in period 0. Then, costs are incurred in periods 1 through n and delivery occurs in period n .¹ It will be assumed that costs are incurred at the beginning of each period and delivery occurs at the end of period n . The costs to be incurred during each period are known only randomly at time 0. Let \tilde{C}_t be the random cost to be incurred at time t and \tilde{C} denote the aggregate random cost.

$$\tilde{C} = \sum_{t=1}^n \tilde{C}_t . \quad (4.1)$$

Let C_t and C denote the realizations of \tilde{C}_t and \tilde{C} . It will be assumed for the bulk of this section that the delivery date n is known and non-random. The implications of allowing a random delivery date will be briefly discussed in Subsection D.

The contract is assumed to be of the following form. Let $p(C)$ denote government's promised payment to the firm contingent on the cost outcome C . This is given by

$$p(C) = \pi + E(\tilde{C}) + (1 - \gamma)[C - E(\tilde{C})] . \quad (4.2)$$

As explained in Sec. 2, the constant π is the profit and γ is the firm's share of the risk of cost overruns and underruns. Finally, let α denote the progress payment rate where $\alpha \in [0, 1]$. Government agrees to pay the fraction α of the contractor's costs immediately as they are incurred.² These payments will then be deducted from the payment of $p(C)$ at the time of delivery.

¹Recall that the symbol ℓ denotes the length of the contract in years. Since the periods need not be one-year long, a different symbol, n , will be used for the number of periods the contract lasts. In real applications, the periods are likely to be one month long. Recall from Sec. 3 that the risk-free rates are described as the return per period. Thus, for one-month periods r_F is 1/12 of the annualized rate.

²The main body of the report will thus consider the rule used under fixed-price-type contracts where progress payments are made only on costs and not on profit. In Sec. 9 it will be shown that an extremely simple adjustment to the profit rule is required when progress payments are made on profit as well.

Formally, a contract can be viewed as a triple (π, γ, α) .

Definition:

A contract is a triple $(\pi, \gamma, \alpha) \in \mathbb{R} \times [0, 1]^2$ where π and γ are the coefficients determining the payment rule, Eq. (4.2), and α is the progress payment rate.

The time sequence of events can be summarized as follows.

Period 0: A contract (π, γ, α) is signed. Government and the firm both know the distribution of the random variables

$$\{\tilde{C}_t\}_{t=1}^n.$$

Period t: The realization of \tilde{C}_t , denoted by C_t , occurs. The firm spends C_t dollars. Government immediately gives the firm αC_t dollars.

Period n: The item is delivered. Government pays the firm $p(C) - \alpha C$ dollars.

To apply the CAPM, the covariance of costs with market returns must be described. Let \tilde{r}_M^t denote the market return at time t . In general, one would expect \tilde{C}_t to be potentially correlated with all market returns up to and including time t . This will be allowed for in the model. However, one simplifying assumption is needed. This is that each period's cost can be divided into additively separable components, such that each market return affects a different component. Formally, assume that

$$\tilde{C}_t = \sum_{i=1}^t \tilde{C}_t^i, \quad (4.3)$$

where

$$\text{cov}(-\tilde{C}_t^i, \tilde{r}_M^j) = 0 \quad \text{for } j \neq i. \quad (4.4)$$

This means that

$$\text{cov}(-\tilde{C}_t, \tilde{r}_M^i) = \text{cov}(-\tilde{C}_t^i, \tilde{r}_M^i) \quad (4.5)$$

for every $i \leq t$.

For cost risk to be negatively valued by the CAPM formulas, it must be the case that costs covary negatively with market returns, i.e., when market returns are high a firm experiences low costs on the contract and thus higher returns on its project. Thus, profit on the contract covaries positively with the market return. This positive covariance of profit on the contract with profit on the market return is what causes the cost risk to be negatively valued by the CAPM. Therefore, it will be assumed that

$$\text{cov}(-\tilde{C}_t, \tilde{r}_M^i) > 0 . \quad (4.6)$$

It will be useful to introduce a parameter to measure the amount of covariance relative to the mean for each random variable. Let

$$\mu_t = \frac{\lambda \sum_{i=1}^t \text{cov}(-\tilde{C}_t, \tilde{r}_M^i)}{E(\tilde{C}_t)} , \quad (4.7)$$

where λ is the parameter in the CAPM formula described in Sec. 3. A larger value of μ_t will be interpreted as meaning that \tilde{C}_t is more risky given its size.

Note that assumption (4.6) is somewhat controversial. If cost risk simply represents scientific and engineering uncertainty about how a particular technical problem will be solved, costs should be uncorrelated with market returns. However, some cost risk is caused by uncertain input prices. It is not clear *a priori* whether one would expect input prices to be positively or negatively correlated with market returns. Both are possible. For example, a drop in energy and commodity prices might cause higher market returns. This is the case consistent with Eq. (4.6). However, an increase in economic activity might also plausibly cause input prices to rise. In this case, input prices would covary positively with market returns. Thus, it seems that in general the covariance of costs with market returns will be much smaller in absolute value than the variance of costs and could conceivably be positive in some cases.

Two points should be noted regarding this. First, the risk premiums allowed by the DoD on contracts are relatively small, ranging between 2.3 percent and 5.1 percent of expected costs. Given the mammoth cost uncertainties present in some projects, one might initially think that these risk premiums are rather low. However, the explanation may be that only systematic risk is priced and the level of

systematic risk is much lower than the total risk; i.e., a large component of the risk is simply technical risk, which is uncorrelated with market returns and is therefore unpriced.

Second, it may be that defense firms negatively value both systematic and nonsystematic risk because of bankruptcy costs or managerial preferences. This could be modeled by substituting

$$\sqrt{\text{var}(\tilde{C})}$$

for $\text{cov}(\tilde{C}, \tilde{r}_M)$ in the CAPM formulas. Exactly the same pricing formulas can be derived under this alternative assumption. Thus, one can interpret the parameters μ_t as meaning all risk and not just systematic risk, if one desires.

The issue of how to interpret the risk parameters μ_t will be returned to in Subsection F.

B. CALCULATION OF THE MINIMUM PROFIT RULE

This subsection uses the CAPM to calculate the present discounted value of a contract to the firm at time 0. Denote this by $V(\pi, \gamma, \alpha)$. Government must choose the profit level so that $V(\pi, \gamma, \alpha)$ is nonnegative for the firm to accept the contract. The smallest such profit will be called the minimum profit rule.

Definition:

The minimum profit rule, denoted by $\pi(\gamma, \alpha)$, is defined by

$$\pi(\gamma, \alpha) = \min\{\hat{\pi}: V(\hat{\pi}, \gamma, \alpha) \geq 0\} . \quad (4.8)$$

The main purpose of this subsection is to calculate the minimum profit rule.

Some notation will be useful to present this result. Let $z(t)$ denote the accumulated return per dollar (in excess of the principal) that an investment at the risk-free rate would yield if the investment were made from periods t through n . This is defined by

$$z(t) = \left[\prod_{i=t}^n (1 + r_F^i) \right] - 1 . \quad (4.9)$$

Now let F denote the amount of money a risk-neutral individual would have to be paid at time n to agree to finance all of the firm's expenditures during the performance period. This will be called the risk-neutral financing cost. It is calculated as follows. At time t the firm expects to spend $E(\tilde{C}_t)$ dollars. This expenditure must be financed for $\ell - t$ periods. Therefore, the present discounted value of financing costs calculated at time ℓ is given by

$$F_t = E(\tilde{C}_t)z(t) . \quad (4.10)$$

Summation over t yields

$$F = \sum_{t=1}^n E(\tilde{C}_t)z(t) . \quad (4.11)$$

Finally, two different sets of weights that sum to one will be defined as follows.

$$a_i = \frac{E(\tilde{C}_i)}{\sum_{t=1}^n E(\tilde{C}_t)} \quad (4.12)$$

and

$$b_i = \frac{F_i}{\sum_{t=1}^n F_t} . \quad (4.13)$$

The term a_i is simply the fraction of costs expected to be incurred during period i . The term b_i is the fraction of financing costs expected to result from period i expenditures.

Now, Proposition 2 presents the minimum profit rule.

Proposition 2:

The minimum profit rule is given by

$$\pi = \gamma \phi E(\tilde{C}_t) + (1 + \psi)(1 - \alpha)F, \quad (4.14)$$

where

$$\phi = \sum_{i=1}^n a_i \mu_i \quad (4.15)$$

and

$$\psi = \sum_{i=1}^n b_i \mu_i. \quad (4.16)$$

Proof:

See App. A. Q.E.D.

The minimum profit rule is therefore the sum of two components. This result is most clearly interpreted by viewing the contract between the firm and government as two separate contracts. Each component of Eq. (4.14) is the profit for one of these two contracts. The two contracts will be called the pure production contract (PPC) and the pure financing contract (PFC).

In the PPC the firm agrees to 100 percent progress payments. The sequence of events is then as follows:

- | | |
|----------------------------|--|
| Period 0: | The contract is signed. |
| Period t:
t = 1, ..., n | The realization of \tilde{C}_t , denoted by C_t , occurs. However, government pays all production costs. |
| Period n: | The item is delivered. Government pays the firm |

$$\pi_{\text{PPC}} + \gamma [E(\tilde{C}) - C].$$

(If this number is negative the firm pays government money.)

By substituting $\alpha = 1$ into Eq. (4.14), the second term of Eq. (4.14) vanishes. Thus, the profit for the PPC is the first term of Eq. (4.14).

In the PFC, the firm agrees to supply $(1 - \alpha)$ of the financing for the contract but to be responsible for no cost overruns or underruns. The sequence of events is thus as follows.

- Period 0: The contract is signed.
- Period t : The realization of \tilde{C}_t , denoted by C_t , occurs. The firm
 $t = 1, \dots, n$ gives government $(1 - \alpha)C_t$ dollars and government
 pays all production costs.
- Period n : Government gives the firm $(1 - \alpha)C + \pi_{\text{PFC}}$.

Thus the firm simply acts as a banker in the PFC. By setting $\gamma = 0$ in Eq. (4.14), the first term of the equation vanishes. Thus, the profit for the PFC is the second term of Eq. (4.14).

The profit required for the PFC will often be referred to as the cost of working capital or the profit for working capital, since this is the term used by the current regulations.

The first term of Eq. (4.14) is therefore the payment the firm receives for bearing the risk of cost overruns and underruns. The parameter ϕ is a measure of the amount of cost risk per unit of expected cost. Thus, $\phi E(\tilde{C})$ is a measure of the total amount of cost risk. The firm bears γ of this risk and thus receives $\gamma \phi E(\tilde{C})$.

The second term of Eq. (4.14) is the payment the firm receives for agreeing to supply contract financing. A risk-neutral firm would require a profit of $(1 - \alpha)F$. The actual required profit is ψ times higher than this. Thus, ψ is a risk premium attached to the financing contract. Initially, this might seem strange. The financing contract involves no default risk. The firm is always paid back the amount it lends plus a fixed profit. Yet the financing contract is risky because the firm is not sure exactly how big a loan it will be required to make; the size of the loan depends on the value of cost. To agree to bear this risk the firm must be paid more than the expected financing cost. Thus, as costs become more risky the PFC also becomes more risky.

Although the risk premiums for the PPC and PFC are both determined by the amount of cost risk, they are not in general the same, as indicated by Eqs. (4.15) and (4.16). They are both weighted averages of the risk parameters $\{\mu_t\}_{t=1}^n$, where μ_t measures the risk of period t costs. Because the PPC is affected by aggregate costs but not their timing, the risk parameter for this contract uses weights equal to the share of cost expected to be incurred each period. Because the PFC is concerned with financing cost, the risk parameter for this contract

uses weights equal to the share of financing cost expected to be incurred each period.

Although no perfectly general statements can be made about the relative magnitudes of ϕ and ψ , Proposition 3 presents an extremely useful description of some cases where they can be compared.

Proposition 3:

Suppose that μ_t is weakly increasing (constant; weakly decreasing) in t . Then $\phi \geq (=; \leq) \psi$.

Proof:

See App. B. Q.E.D.

The reason for Proposition 3 is extremely simple. Expected financing cost is larger in earlier periods for a given level of expected production costs because interest compounds for more periods. Thus, the $\{b_t\}$ weights will be larger than the $\{a_t\}$ weights for small values of t and smaller than the $\{a_t\}$ weights for large values of t . If the values of μ_t are larger for small values of t , the $\{b_t\}$ weights will produce a larger average value. Similarly, if the values of μ_t are larger for large values of t , then the $\{a_t\}$ weights will produce a larger average value. In more economic terms, cost risk in early periods is relatively more important for the PFC, since this risk is magnified by many periods of compounding. Thus, if early period cost is more risky, the PFC will exhibit a larger risk parameter. If later period cost is more risky, the PPC will exhibit a larger risk premium.

Probably the most plausible economic assumption is that cost risk is weakly increasing over time, because events further in the future are likely to be more uncertain. In this case, Proposition 3 states that ϕ is (weakly) greater than ψ .

Appendix C calculates the size of ψ relative to ϕ for the case where costs are incurred uniformly, risk is assumed to grow exponentially over time at the rate θ per year, and the contract is ℓ years long. The ratio ψ/ϕ is calculated for various values of θ and ℓ . If risk grows at 10 percent per year, the effects are very small; i.e., ψ/ϕ is nearly equal to one. However, if risk grows at 100 percent or 200 percent per year, the effects can be quite large. Ratios of 1/2 or less are possible.

C. DELAYS

This subsection will briefly conjecture how the existence of a random delivery date would qualitatively affect the results of the previous

subsection. The technical difficulty in deriving simple tractable formulas as in the previous subsections is that contract length and cost are probably positively correlated. This generates extremely complicated formulas that are difficult to interpret. Furthermore, the delivery date \bar{n} does not enter linearly into the valuation formulas.³ Therefore, the expected delivery date $E(\bar{n})$ does not appear naturally in the resulting minimum profit rule. This means that it is not possible to write the minimum profit rule as a function of the expected costs and expected delivery date. Since the actual regulatory formula for profit is a function of estimated cost and estimated delivery date, there is no obvious correspondence between the correct and actual formulas by interpreting expected values in the correct formulas as estimated values.

One simple *ad hoc* approach to modifying the minimum profit rule formula to allow for delay risk is to follow a certainty equivalent approach. Suppose that delay risk can be accounted for by calculating profit under the assumption that delivery will occur with certainty at date $(1+\xi)n$; i.e., this will be a delay of $\xi \times 100$ percent. (For simplicity assume that costs will still be incurred at times 1 through n as anticipated. Thus the only change is that the delivery date is pushed back $\xi \times 100$ percent.) In this case, the correct minimum profit rule is given by Eq. (4.14) with $(1+\xi)n$ replacing n .

Some additional notation is useful to formally state the new rule. Define $G(t)$ as the risk-neutral financing cost if delivery occurs at time t . This is given by

$$G(t) = \sum_{i=1}^n E(\tilde{C}_i) \left\{ \left[\prod_{j=i}^t (1 + r_F^j) \right] - 1 \right\} . \quad (4.17)$$

Then, the minimum profit rule is given by

$$\pi = \gamma \phi E(\tilde{C}) + (1 - \alpha)(1 + \psi)G((1 + \xi)n) , \quad (4.18)$$

where ϕ and ψ are the cost risk premiums defined by Eqs. (4.15) and (4.16) and ξ is the delay risk premium.

Note that in Eq. (4.18) delay risk affects only the second term of the formula. That is, delay risk does not affect the profit required by the

³A superscript \sim is placed over n to indicate that it is now a random variable.

PPC. It affects only the profit required by the PFC. This is intuitively reasonable. The PPC has all cash payments and receipts occur on the delivery date. That is, on the delivery date the firm pays \bar{C} dollars and receives $\pi_{PPC} + E(\bar{C}) + (1 - \gamma)(\bar{C} - E(\bar{C}))$ dollars. The value of π_{PPC} that the firm must be paid to accept this gamble is independent of the delivery date.

The major qualitative difference between the simple rule derived above and a fully correct rule that explicitly considers the randomness of \bar{n} would be that the profit on the PPC might also be affected. If \bar{n} is random but independent of \bar{C} it is easy to show that the required profit on the PPC is *not* affected by \bar{n} . That is, a rule of the form of Eq. (4.18) will be optimal. However, when \bar{n} covaries positively with \bar{C} (as seems reasonable), the required profit on the PPC will be affected by the randomness of \bar{n} . Somewhat surprisingly, the effect seems likely to be negative; i.e., as \bar{n} becomes more risky the required profit on the PPC goes down. The reason for this is that when costs are high (low) and profits are therefore low (high), the realization of profits will occur later (sooner). That is, the positive correlation of \bar{C} and \bar{n} means that low profits will be realized later and high profits will be realized sooner, which is good from the firm's point of view. Thus as \bar{n} grows more variable this may cause profits for the PPC to go down.

Thus, the major qualitative difference between the simplified rule in Eq. (4.18) derived above and a fully correct rule would probably be that the latter would allow for delay risk to result in a reduction of the first term (π_{PPC}) as well as an increase in the second term (π_{PFC}).

D. PRACTICAL IMPLEMENTATION

If a contracting officer could produce separate precise estimates for each of the risk parameters $\{\mu_t\}_{t=1}^n$ and ξ , then the formula derived in the previous subsections could be used in the actual regulations. However, in reality a contracting officer can probably only estimate whether the contract risk as a whole is high relative to the "average" contract. Probably in general, contracts with high levels of cost risk have high levels for all periods and also have high delay risk. Thus, it might not even be very useful to attempt to distinguish between the $n + 1$ different parameters even if it were possible to do so. However, this is probably a moot question because it is unlikely that contracting officers could make this type of estimate.

Thus a "practical" formula should probably simply include one risk parameter that the contracting officer is asked to estimate.

Regulations could specify an average value, an allowed range, and conditions that should cause the officers to choose above- or below-average values. Furthermore, the average value and allowed range could be made functions of objectively verifiable features of the contract, such as its length, if desired. This subsection suggests the form that such a one-parameter rule might take.

To do this it is useful to first summarize the major qualitative implications of the theoretical model in the previous subsections. One can think of the contract as actually consisting of two separate contracts, the PPC and the PFC. In the absence of risk, only the PFC requires a positive profit. This is the expected financing costs of the contractor. Two types of risk enter into the firm's calculation, however. First, there is cost risk, which affects both the PPC and the PFC. If all periods' costs are equally risky, the aggregate impact of this risk (viewed as a percentage risk premium) should be the same on both contracts. However, if later periods are more risky than earlier periods, cost risk will have more of an impact on the PPC. The second type of risk is delay risk. The major effect of delay risk is on the PFC, since the PPC is timeless.

As argued above, it is probably impractical to expect the contracting officer to be able to reliably estimate anything more than some joint measure of whether both types of risk are high or not. Without further empirical work there seems to be little reason to choose a rule that does not make the same risk adjustment to both contracts. That is, the suggested rule is

$$\pi = \gamma \omega E(\tilde{C}) + \omega(1 - \alpha)F, \quad (4.19)$$

where ω is the risk parameter. When costs in every period are equally risky and there is no delay risk, this is exactly correct. When costs in periods further in the future are more risky, the relative risk premium paid to the PFC should be reduced somewhat. However, when there is delay risk, the risk premium paid to the PFC should be increased somewhat. It is not clear that these effects cancel. However, without any empirical work, the theory suggests only that both contracts require risk premiums. The simplest formula assigns the same percentage risk premium to both.

Obviously, an important topic for future research would be to develop some empirical basis for choosing a regulatory formula of the form

$$\pi = \gamma \omega E(\tilde{C}) + g(\omega)(1 - \alpha)F, \quad (4.20)$$

where g is some function (probably linear) specified in the regulation. It should be possible to do this. For example, if one had data on the expected and actual cost and delivery outcomes for a set of contracts, one could calculate the variance in profits for the PPC and PFC separately. If the standard deviation in the PFC was found to be β times the standard deviation of the PPC, this might suggest that $g(\omega)$ in Eq. (4.20) be chosen as

$$g(\omega) = \beta\omega . \quad (4.21)$$

It is important to note that the simple rule of adding a risk premium only to one of the two terms would not be satisfactory. First consider a rule of the form

$$\pi = \gamma\omega E(C) + (1 - \alpha)F . \quad (4.22)$$

This is essentially the form of the current rule. The problem with this rule occurs for risky projects where γ is chosen to be very low. For these cases, the PPC bears very little risk because γ is low. However, the PFC is very risky. A rule of the form of Eq. (4.22) would not adequately compensate high-risk projects where γ is low. Now consider a rule of the form

$$\pi = (1 + \omega)(1 - \alpha)F . \quad (4.23)$$

The problem with this rule is that contracts in which the contractor bears none of the PPC risk (i.e., $\gamma = 0$) receive the same profit as contracts in which the contractor bears all of it (i.e., $\gamma = 1$). This is also obviously unsatisfactory.

Thus, a good rule must encourage the contracting officer to realize that risk affects both the PPC and the PFC, because variations in γ affect the share of risk the contractor bears on the PPC but not on the PFC. Thus, the two impacts of risk must be separately identified to correctly calculate how variations in γ affect the total amount of risk the contractor is exposed to. Whether the risk premium on both contracts should be exactly the same is an empirical issue that should be investigated. In the absence of other information, this seems to be a reasonable course of action.

E. THE ROLE OF THE CAPM

The fact that a contract can be decomposed into two simpler contracts—the PPC and the PFC—is perfectly general and does not depend on the CAPM. Each component contract is relatively simple and it is possible to describe a number of plausible properties that the rules for calculating profit for each of the two components ought to exhibit. The role of the CAPM analysis is to provide a formal derivation of a set of simple linear formulas that exhibit these properties.

The one special result of the CAPM formulation regards the distinction between diversifiable and nondiversifiable risk. Given the CAPM assumption that all investors hold a well-diversified portfolio, it follows that there is no need to reimburse the firm for exposure to diversifiable risk. This conclusion has profound implications for the pricing of defense contracts, since much of the risk of defense contracts is of a scientific or technical nature and is thus completely diversifiable.

Fortunately, the issue of whether to interpret the risk parameters as measures of all risk or merely nondiversifiable risk appears to be relatively separable from the issue of whether the formulas are valid in other respects. On a broad qualitative level, many other properties of the formulas follow fairly naturally on an intuitive level from the decomposition of the contract into the PPC and the PFC. With respect to the precise linear form, the same formulas can be derived by assuming that the firm maximizes a discounted utility function that is linear in mean and standard deviation. Then, the risk parameters, μ_t , are determined by the variance of costs instead of the covariance of costs with the market portfolio.

5. THE IRR UNDER THE CORRECT PROFIT RULE

A. BACKGROUND

Suppose that profit is calculated for a contract by the minimum profit rule of the last section. One could then calculate the IRR that the contract yields. This is simply defined to be the discount rate such that the net present value of all expected cash flows equals zero. Formally, it is defined by¹

$$\sum_{t=1}^n -\frac{(1-\alpha)E(\bar{C}_t)}{(1+q)^t} + \frac{(1-\alpha)E(\bar{C}) + \pi}{(1+q)^n} = 0, \quad (5.1)$$

where π is the minimum profit calculated according to Eq. (4.14) and q denotes the IRR.

Now suppose that the risk coefficients for all contracts were drawn from a one-parameter family

$$\{\mu_t(\theta)\}_{t=1}^{\infty} \quad (5.2)$$

where θ is a nonnegative real number. That is, any contract of length ℓ is of some type θ . A type θ contract, which is n periods long, has risk parameters given by

$$\{\mu_t(\theta)\}_{t=1}^{\infty}.$$

Interpret θ as a measure of risk. That is, assume that

$$\mu_t(0) = 0 \quad (5.3)$$

and

$$\mu'_t(\theta) > 0 \quad (5.4)$$

¹It may be that multiple solutions to Eq. (5.1) exist for some patterns of cost incurrence. This problem will be ignored here, since the point of this subsection is to show that the IRR concept is not useful even when it is well defined.

for every t . A plausible specification of the risk parameter functions would probably also have risk weakly increasing over time. That is, it should also be assumed that

$$\mu_t(\theta) \geq \mu_{t-1}(\theta) \quad (5.5)$$

for every t .

Now consider any contract of length n . Let $\pi^n(\theta, e_1, \dots, e_n, \alpha, \gamma)$ denote the minimum profit calculated according to Eq. (4.14) for a contract of length n where the expected value of period t costs is e_t , the risk parameter for period t costs is $\mu_t(\theta)$, the progress payment rate is α , and the contractor's share of the risk is γ . Finally, let

$$\Gamma^n(\theta, e_1, \dots, e_n, \alpha, \gamma)$$

denote the IRR for this contract calculated by Eq. (5.1).

Then, it would be extremely interesting if one could prove the following conjecture.

Conjecture:

There exists a one-parameter family of risk coefficients as defined by Eq. (5.2) which satisfies Eqs. (5.3) – (5.5) such that

- (i) $\Gamma^n(\theta, e_1, \dots, e_n, \alpha, \gamma)$ depends only on θ . Denote this function by $\Gamma^n(\theta)$.
- (ii) $\Gamma^n(\theta)$ is the same function for every n . Denote this common function by $\Gamma(\theta)$.

Suppose this conjecture were true. Then, in a world where contract risk could be described by this one-parameter family, contract officers could be asked to simply choose a discount rate r and to choose a higher discount rate for riskier contracts. (Implicitly, contracting officers would be asked to estimate θ for the contract in question. The discount rate chosen would then be $\Gamma(\theta)$.) Then, the correct profit for the contract could be calculated by choosing a profit such that the expected discounted value of all cash flows is zero using the chosen discount rate. Thus, profit policy would essentially tell contract officers to fix an IRR according to their estimate of risk and to choose profit so that this IRR is achieved. As described in Sec. 4, an average value and minimum and maximum values could be set.

Some evidence exists *a priori* to make this a plausible conjecture. Introductory finance texts always consider a particularly simple investment problem where a firm invests a certain amount in period 0 and receives uncertain cash inflows in periods 1 through n . They show that the appropriate version of the above conjecture is true for this problem. Namely, if risk increases exponentially with time then the correct method for calculating the value of the project is to discount all expected cash flows at a discount rate greater than the risk-free rate. Furthermore, the discount rate is independent of the pattern of expected cash inflows.

The conclusion of this section, however, is that the conjecture is definitely false; so are most weaker versions of it. This is demonstrated in two steps. Subsection C shows that the approach used in the finance literature of assuming that risk increases exponentially with time produces a different and more complicated result in the investment problem of this report. The correct calculation of value discounts expected costs by a discount rate *less* than the risk-free rate and discounts all delay in reimbursement at *exactly* the risk-free rate. In particular, there is no sense in which it is appropriate to use a single discount factor *greater* than the risk-free rate to discount all cash flows.

Subsection D directly calculates how the IRR varies as the parameters α , γ , and n vary. It is shown that the IRR formula is essentially measuring a "nonsense" value for the firm's contracting problem and thus the IRR generated by the correct profit rule may in fact move in what appears to be very strange fashions as α and γ vary. No general theoretical predictions about the way the IRR should vary with length are possible. If longer contracts are no more risky than shorter contracts, then the IRR should decline with contract length. However, if risk increases fast enough with contract length, then perhaps the IRR should be constant or increase. This is an empirical question.

B. EXPONENTIALLY INCREASING RISK

For simplicity it will be assumed for the rest of this section that the risk-free rate is constant over time. Let r_F denote this value.

The standard investment problem considered by finance texts has a firm spend a certain sum, p , at time 0 and then receive the uncertain positive cash flow, \tilde{C}_t at time t for $t \in \{1, \dots, n\}$. Applying the CAPM framework, the net present value is given by

$$V = -p + \sum_{t=1}^n \frac{(1-\mu_t)E(\tilde{C}_t)}{(1+r_F)^t}, \quad (5.6)$$

where the μ_t are risk parameters derived much as in Sec. 4. Each μ_t is positive because the uncertain cash flow is valued at less than its expected value. Larger values of μ_t mean that the risk is greater.

Now suppose that risk increases exponentially over time. In particular, assume that

$$(1-\mu_t) = \frac{(1+r_F)^t}{(1+r)^t} \quad (5.7)$$

for some $r > r_F$. Substitution of Eq. (5.7) into Eq. (5.6) yields

$$V = -p + \sum_{t=1}^n \frac{E(\tilde{C}_t)}{(1+r)^t}. \quad (5.8)$$

That is, if risk increases exponentially as described in Eq. (5.7) and the firm is aware of this, then it should use an IRR rule setting the IRR equal to r to evaluate whether to accept the project. Note that $r > r_F$. This means that returns further away are discounted more heavily. This is intuitively reasonable because returns further away are riskier.

The above example is absolutely standard in most introductory finance texts.² This might lead one to intuitively suspect that a similar result could be derived for the case of interest to this report. That is, in the model of Sec. 4, if risk increases exponentially then is it appropriate to use an IRR rule with $r > r_F$ to evaluate the net present value of the contract? The answer, unfortunately, is no. To explain why, the above example will be transformed in two steps to more closely resemble the problem we are interested in.

First, suppose that the firm *receives* p dollars at time 0 (where p is positive) and then faces an uncertain *expenditure* flow of

$$\{\tilde{C}_t\}_{t=1}^n.$$

²See, for example, Brealey and Meyers (1988). See Fama (1977) for a more advanced treatment.

In this case, the net present value will be given by

$$V = p - \sum_{t=1}^n \frac{(1+\mu_t)E(\tilde{C}_t)}{(1+r_F)^t} \quad (5.9)$$

Just as before, the μ_t are nonnegative and higher values of μ_t denote higher values of risk. Note that now the risk adjustment to expected values is made by multiplying by one *plus* μ_t . That is, for the risk of a cash outflow to be negatively valued by the firm, the certainty equivalent must be greater than the expectation. For the case of a cash inflow the reverse is true. For the risk of cash inflow to be negatively valued by the firm, the certainty equivalent must be less than the expected value. This explains why the minus sign of Eq. (5.6) must be changed to a plus sign in Eq. (5.9).

Now, to derive an IRR type of rule we must assume that μ_t satisfies

$$(1+\mu_t) = \frac{(1+r_F)^t}{(1+r)^t} \quad (5.10)$$

for some r . Furthermore, since $\mu_t \geq 0$, it must be the case that r is *less* than r_F not *greater* than r_F . Given the assumption that r is *less* than r_F , it is true that the values of μ_t are increasing.

This means that when risk increases exponentially for the case of uncertain cash outflows, it is appropriate to use an IRR rule, but the discount rate should be chosen to be *less* than the risk-free rate. This is intuitively reasonable. When risk increases exponentially one wants to weight future cash outflows more highly. This is done by using a lower discount rate. Once again, this point is absolutely standard in introductory finance texts.³

Now, alter the above example in one more fashion. Assume that the cash outflows

$$\{\tilde{C}_t\}_{t=1}^n$$

still occur as above, only assume that the certain cash inflow occurs at time n . This, of course, corresponds to an FFP contract with no

³See Brealey and Meyers (1986), pp. 79–80.

progress payments (i.e., $\alpha = 0$ and $\gamma = 1$). Then, the CAPM would calculate net present value by the formula

$$V = - \sum_{t=1}^n \frac{(1+\mu_t)E(\tilde{C}_t)}{(1+r_F)^t} + \frac{p}{(1+r_F)^n} \quad (5.11)$$

Now, suppose that risk increases exponentially. That is, suppose that μ_t satisfies Eq. (5.10) for some $r < r_F$. Then Eq. (5.11) becomes

$$V = - \sum_{t=1}^n \frac{-E(\tilde{C}_t)}{(1+r)^t} + \frac{p}{(1+r_F)^n} \quad (5.12)$$

Thus, the correct rule discounts expected cash outflows by a discount rate r less than the risk-free rate and discounts the inflow by the risk-free rate. However, there is no sense in which it is appropriate to discount all cash flows by some interest rate greater than r_F .

Of course, this same property continues to hold for the more general contracting problem where $\alpha \neq 0$ and $\gamma \neq 1$. Equation (5.10) can be substituted into Eqs. (4.14)–(4.16) to yield the correct pricing formula. Intuitively, the correct formula discounts costs at the rate $r < r_F$ until they occur and accounts for all delays in payment and reimbursement at the risk-free rate r_F .

C. COMPARATIVE STATICS OF THE IRR

The correct price for the example described by Eq. (5.12) is calculated by setting the net present value equal to zero. Let p^* denote the correct price. It is defined by

$$0 = - \sum_{t=1}^n \frac{E(\tilde{C}_t)}{(1+r)^t} + \frac{p^*}{(1+r_F)^n} \quad (5.13)$$

One could now calculate the IRR generated by this contract. It is defined by

$$0 = - \sum_{t=1}^n \frac{E(\tilde{C}_t)}{(1+q)^t} + \frac{p^*}{(1+q)^n} \quad (5.14)$$

where p^* is obtained from Eq. (5.13). However, the IRR thus calculated is essentially a "nonsense number." It is a complicated function of r , r_F , and the time pattern of costs and has no natural economic interpretation. This subsection will show that the IRR for the correct pricing rule exhibits extremely bizarre behavior as various parameters of the contracting problem change. The IRR exhibits this behavior even though the pricing rule is perfectly correct. This will show that attempting to evaluate the appropriateness of profit policy regulations by evaluating the IRR they generate may be extremely misleading and not very useful.

Consider a very simple contract where all costs are incurred at time m and delivery occurs at time $2m$. Since it will be interesting to conduct comparative statics on α and γ , these will not be set equal to 0 and 1 but will rather be allowed to assume arbitrary values.

Then the correct profit rule is given by⁴

$$\pi = \gamma \mu E(\tilde{C}) + (1 + \mu)(1 - \alpha) E(\tilde{C}) [(1 + r_F)^m - 1] . \quad (5.15)$$

The IRR yielded by the correctly priced contract is defined by

$$-(1 - \alpha) E(\tilde{C}) + \frac{\pi + (1 - \alpha) E(\tilde{C})}{(1 + q)^m} = 0 , \quad (5.16)$$

where π is determined by Eq. (5.15). Rewrite this as

$$(1 + q)^m = \frac{\pi + (1 - \alpha) E(\tilde{C})}{(1 - \alpha) E(\tilde{C})} . \quad (5.17)$$

Substitution of Eq. (5.15) into Eq. (5.17) yields

$$(1 + q)^m = \frac{\gamma \mu}{(1 - \alpha)} + (1 + r_F)^m + \mu [(1 + r_F)^m - 1] . \quad (5.18)$$

Equation (5.18) defines the IRR that a correctly priced contract would exhibit for various values of α , γ , and m . It will now be shown that

⁴Since all costs are incurred at time m , the subscript m has been dropped from \tilde{C} and μ .

the IRR varies in extreme and often what superficially appear to be "incorrect" ways as these parameters vary. However, this is simply a reflection of the fact that the IRR is not a particularly useful or natural way to think about this contracting problem. Comparative statics for each parameter will now be considered in turn.

The basic economic reason for all three results is the same and it will be described first before presenting the comparative statics results. Profit contains a fixed payment of

$$\gamma\mu E(\bar{C}) \quad (5.19)$$

for the PPC independent of the amount of financing that the firm is asked to supply. The IRR calculation essentially divides all profit, including the PPC profit, by the amount of contractor-supplied financing to calculate a rate of return. However, the profit on the PPC is totally unrelated to the amount of financing.

To put this more explicitly, one could separately calculate the IRR on the PPC and the PFC. These are defined by the first and second terms of Eq. (5.18).

$$(1 + q_{PPC})^m = \frac{\gamma\mu}{(1 - \alpha)} \quad (5.20)$$

$$(1 + q_{PFC})^m = (1 + r_F)^m + \mu \left[(1 + r_F)^m - 1 \right] \quad (5.21)$$

The IRR of the contract as a whole is thus determined by the IRR on each of its two component contracts. The IRR on the PFC is a relatively well-behaved number because it has a natural economic interpretation. It is equal to the profit on the financing contract expressed as a return on the amount of contractor-supplied financing. However, no sensible interpretation exists for the IRR on the PPC. It equals the profit on the PPC expressed as a return on the amount of contractor-supplied financing. However, the required profit on the PPC is totally independent of the amount of contractor-supplied financing.

The comparative statics properties of the IRR will now be described.

The Effect of α on IRR

From Eq. (5.18) it is clear that the IRR equals a number bigger than r_F when $\alpha = 0$ and grows to ∞ as α grows to 1. Therefore, a correctly priced contract should exhibit a larger IRR as the progress payment rate grows. A cost-type contract that receives 100 percent progress payments should exhibit an infinite IRR, as explained above. The IRR on the PPC expresses PPC profit as a return on contractor-supplied financing. Profit on the PPC is not affected by the amount of contractor-supplied financing. Thus, as contractor-supplied financing goes to zero (because α goes to 1) the IRR on the PPC goes to infinity. This in turn causes the IRR for the contract as a whole to go to infinity.

The Effect of γ on IRR

From Eq. (5.18) it is clear that the IRR equals a positive number greater than r_F when $\gamma = 0$ and increases in γ . Thus, if a contracting officer was contemplating whether to set γ equal to 0.5 or 0.8 for a given contract, the correct profit rule would offer the firm a lower IRR when $\gamma = 0.5$ than when $\gamma = 0.8$, as explained above. As γ grows the profit for the PPC contract grows, which raises the IRR on the PPC. This causes the IRR for the contract as a whole to rise.

The Effect of m on IRR

It can be shown that the IRR as defined by Eq. (5.18) is strictly decreasing in m . Furthermore, as m converges to 0 the IRR converges to ∞ ; as m converges to ∞ the IRR converges to r_F . This is illustrated in Fig. 5.1.

The economic reason for this result is once again straightforward. Changing the length of time for which the firm supplies financing essentially changes the "amount" of financing the firm supplies. Thus, when $m = 0$ the firm is supplying no financing and the IRR on the PPC is infinite. This means that the IRR on the contract as a whole is infinite. As m grows extremely large, the IRR on the PPC shrinks to zero. The IRR on the PFC and thus on the contract as a whole converges to the risk-free rate.

One must be careful in interpreting this result, however. It states that if a contract grows longer *but remains equally risky*, its IRR should decline. As discussed in Sec. 4 it is plausible to assume that costs incurred further in the future will involve more risk. In terms

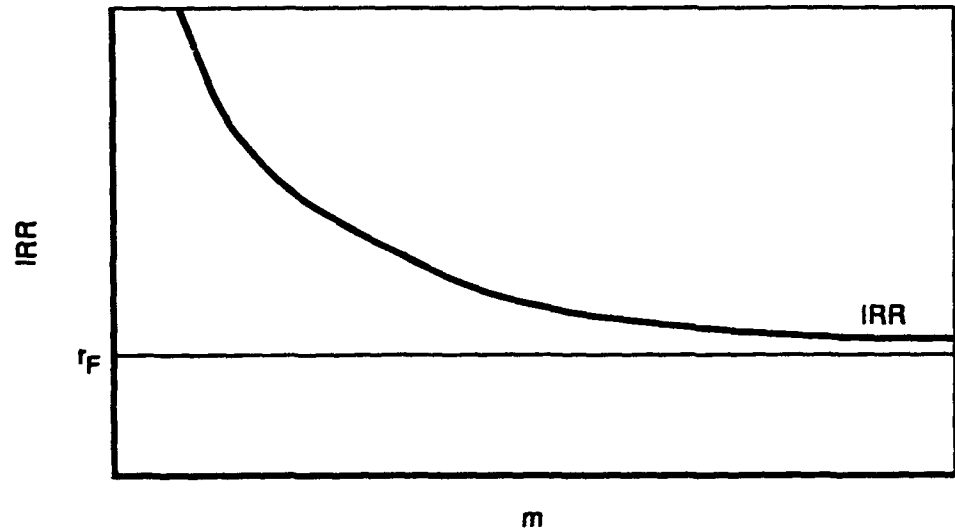


Fig. 5.1—The IRR as a Function of m

of the simple example considered here, one should also allow μ to depend on m . From Eq. (5.18) it is possible to solve for the functional form of μ such that the IRR remains constant as m increases. Suppose that the IRR is constant and equal to k . Then μ must satisfy

$$(1+k)^m = \frac{\gamma\mu}{(1-\alpha)} + (1+r_F)^m + \mu[(1+r_F)^m - 1] . \quad (5.22)$$

Rewrite this as

$$\mu = \frac{(1+k)^m - (1+r_F)^m}{\frac{\gamma}{(1-\alpha)} + (1+r_F)^m - 1} . \quad (5.23)$$

Thus, for a given γ and α , if uncertainty increased exactly as specified in Eq. (5.23), then correctly priced contracts with this γ and α would exhibit a constant IRR. If μ increased faster (slower) than this, then correctly priced contracts with this γ and α would exhibit an increasing (decreasing) IRR. However, it would only be coincidental if the IRR was constant. Furthermore, if the IRR was constant for correctly priced contracts with one value of γ and α then it would not be constant for correctly priced contracts with different values of γ and α .

The Effect of the Time Pattern of Cost Incurrence on IRR

It is also interesting to investigate how the IRR changes as the time pattern of cost incurrence changes within a contract of a fixed length. In particular, how does the IRR change as more of the costs are expected to be incurred earlier in the performance period? A simple example illustrates the key economic factor determining this. Suppose that delivery occurs at a fixed time n . All costs are incurred at time $(n - m)$ where m is the comparative statics parameter. Larger values of m mean that costs are incurred earlier. Upon a moment's reflection it will be clear that formula (5.18) still determines the IRR under the correct profit rule where μ is interpreted as

$$\mu = \mu_{m-n} \quad (5.24)$$

Therefore, as m increases the IRR decreases, holding μ fixed. However, for the plausible case where cost risk is weakly increasing over time, μ weakly decreases in m . Therefore, the IRR decreases in m even when movements of μ are allowed for.

The economic reason for this result is once again straightforward. When costs are shifted into earlier periods, the correct profit rule increases profit by calculating the time value of delay at the risk-free rate. Thus, the IRR is lowered. If risk decreases in earlier periods, the effect is even stronger. To put this another way, shifting cost into earlier periods simply is another way to ask the firm to supply "more" financing. For the reason developed in the previous examples, as the firm supplies more financing itself, the IRR on the PPC goes down. This reduces the IRR on the whole contract.

6. PROFIT FOR RISK

A. INTRODUCTION

This section identifies the component of profit in the profit policy regulations that is probably meant to be the profit paid for the PPC. Recall that Sec. 4 specifies that profit for the PPC should be given by a rule of the form

$$\pi_{\text{PPC}} = \gamma \omega E(\tilde{C}) , \quad (6.1)$$

where ω is a risk parameter.

Two major points are investigated in this section. First, Subsection B shows that there appears to be a rather large error in the manner in which the current regulations instruct that this profit be calculated. Subsection B shows how the rule should be redrafted to be consistent with the results of Sec. 4. Having done this, one can infer what value of ω the current regulations are implicitly specifying. Second, Subsections C and D investigate the issue of whether the regulations should be altered to explicitly make the value of ω depend on contract length. The current regulations do not do this.

B. THE FORM OF THE CURRENT RULE

Recalling that Table 2.5 shows that there are two components of profit, one as a return to risk. These are the "contract risk" component and the "technical risk" component of performance profit.

The contract risk profit can be broken into two parts. First, every contract receives 0.44 percent on average, with a range of 0 percent to 0.88 percent. This will be called the fixed part. Second, contracts that have the firm bear some risk yield an additional return. This will be called the variable part. Tables 6.1 and 6.2 describe these two parts.

Table 6.1
Fixed Contract Risk Profits

Contract Type	Normal Value, %	Allowable Range, %
All contracts	0.44	0 to 0.88

Table 6.2
Variable Contract Risk Profit

Contract Type	Normal Value, %	Allowable Range, %
Firm fixed price	2.20	1.76 to 2.64
Fixed price incentive	0.44	0 to 0.88
Cost plus incentive fee	0.44	0 to 0.88
Cost plus fixed fee	0	0 to 0

Note that technical risk and the fixed part of contract risk do not vary with contract type. In the notation of Sec. 4 where γ is the cost-sharing parameter, these returns do not depend on γ . In contrast, the variable component of contract risk is highly dependent on γ . When γ equals 0, variable contract risk is also 0. As γ grows, variable contract risk is positive. Finally, if γ equals 1, variable contract risk is largest. The rule does not specify that variable contract risk should grow smoothly with γ . Nevertheless, the current rule for determining profit as a return to risk is clearly roughly of the form

$$\pi = [a + \gamma b]E(\tilde{C}) , \quad (6.2)$$

where $E(\tilde{C})$ denotes expected costs. The parameter a consists of the technical risk profit plus the fixed part of contract risk profit. The parameter b is the variable part of contract risk profit. Thus, a and b have the normal values and allowable ranges under the current regulations shown in Table 6.3.

Profit regulations correctly identify the fact that two factors determine the risk a firm bears when it signs a contract. The first is the degree of responsibility for cost overruns that the firm assumes. The regulations call this "contract risk." In the model of Sec. 4 this is represented by the parameter γ . The contractor assumes the share γ of the responsibility. The second factor is the uncertainty of cost at the time of contracting. In a state-of-the-art project with many poten-

Table 6.3
Values of a and b

Parameter	Normal Value, %	Allowable Range, %
a	1.50	0.53 to 2.46
b	2.20	1.76 to 2.64
$a + b$	3.70	2.29 to 5.10

tial technical uncertainties to be resolved, uncertainty will be high. In more standard projects involving well-understood technologies, cost uncertainty will be low. The regulations call this second factor technical risk. In the model of Sec. 4 this is represented by the parameter ω , which is determined by the uncertainty of costs. Projects with more uncertain costs have a higher value of ω .

The fundamental conceptual error made by the current regulations is the assumption that these two factors are somehow additively separable. That is, the regulations assume that a separate return to each element of risk should be calculated and then these two values should be added together to determine the total return to risk. This is, of course, absolutely incorrect. The parameter γ determines the share of the technical risk the contractor is bearing. If $\gamma = 0$ (i.e., the firm has a cost plus fixed fee contract), then the firm is bearing none of the technical risk. A zero share of a very large value is still zero. That is, when $\gamma = 0$ the contractor is not bearing any risk regardless of how uncertain costs are. Thus, the return to risk should be zero. The current regulations offer a normal return of 1.50 percent of expected cost and a maximum return of 2.46 percent of expected cost as a return to risk for a contractor that has signed a cost plus fixed fee contract. However, the contractor is actually bearing a zero share of the risk. Therefore his return should also be zero.

The above point is true in any sensible economic model used to value risk. In the CAPM model of this report, an even more structured and elegant conclusion is derived. Namely, the return to risk the contractor should receive equals the total value of technical risk given by

$$\omega E(\tilde{C}) \quad (6.3)$$

multiplied by the contractor's share of the risk,

$$\gamma . \quad (6.4)$$

Thus, the return to risk is given by

$$\gamma \omega E(\tilde{C}) . \quad (6.5)$$

That is, the contractor's return to risk is calculated by *multiplying* contract risk by technical risk, not by *adding* them. This has a strong intuitive justification, since total risk is simply the share of technical risk that the contractor assumes.

Thus, the form of the current regulations is clearly incorrect. Even its drafters probably did not intend negotiators to follow it exactly as written. Doing so would, for example, create the following outcome. In general, contracts with greater technical risk are assigned lower cost-sharing ratios, i.e., if technical risk is higher, then γ is lower. Thus, in general, the value of γ is a good measure of the level of technical risk of the project. Contracts with lower values of γ have higher levels of technical risk. Thus, literally following the directions of the regulations would require that negotiators give higher values of technical risk profit to contracts where firms bear the least risk! In particular, the projects with highest cost variability are given cost plus fixed fee contracts. Thus, cost plus fixed fee contracts should in general receive the largest amount of technical risk profit according to the regulations as written. Firm fixed-price contracts should in general receive the lowest amount of technical risk profit according to the regulations as written. This topsy-turvy result is surely not what drafters of the regulations intended.

In conclusion, the return to risk should be of the form of Eq. (6.5) as determined by the analysis of Sec. 4. The current rule described by Eq. (6.2) is not of this form. Two possible methods for correcting this situation exist depending upon one's theory of the intent of the drafters of the regulations. One possible theory is that the drafters really intended both a and b to be a return to risk. In this case, ω should be chosen to equal $a + b$. The other possible theory is that drafters of the regulations actually meant a to be something other than a return to risk. In this case, ω should be chosen equal to b and the regulations describing the purpose of a and the reasons for raising or lowering it should be rewritten.

The former theory seems much more plausible for two reasons. First, the regulations clearly label the profit as a return to technical risk and explicitly describe in detail a number of factors that would tend to increase or decrease this risk. Second, and perhaps more important, previous versions of the regulations have all specified much higher values for ω than b . In fact, even $a + b$ is somewhat lower than past values of ω . These data are summarized in Table 6.4. It should be noted that the calculation of ω for past policies may not be totally accurate because of one technical issue described in the footnote to the table. Nonetheless, the value of b is so much smaller than past values of ω that it is hard to believe that drafters of the current regulations intended ω to equal b .

Table 6.4
Values of ω in Past Policies Compared
with b and a + b

	Normal Value, %	Allowable Range, %
1964 policy	3.75	3 to 4.75
1976 revision	4.75	4 to 5.75
1980 revision	4.75	4 to 5.75
b	2.20	1.76 to 2.64
a + b	3.70	2.29 to 5.10

NOTE: Prior to the current policy, working capital costs for fixed-price contracts were not separately accounted for. All previous versions of regulations indicated that a cost-type contract should receive a 2 percent lower return than a fixed-price-type contract with the same sharing ratio. Thus, 2 percent is the implied cost of working capital for fixed-price-type contracts. This is the assumption used in calculating ω in the above table.

Therefore, it seems most likely that the current regulations should be redrafted with $\omega = a + b$. A single section discussing return to risk should replace the two current sections. This is the major change suggested by the analysis of Sec. 4. However, two smaller issues could also be addressed.

First current regulations diverge from Eq. (6.5) in their treatment of contracts with values of γ strictly between 0 and 1. The correct rule described in Eq. (6.5) has the contractor receive a proportionately larger premium as he assumes proportionately more risk. A literal reading of the actual rule states that any contract that has a $\gamma \in (0,1)$ should receive exactly the same profit. A contract that had the contractor bear 0.99 of the risk should receive the same profit as one in which the contractor bears 0.01 of the risk. This is of course nonsense. The drafters of the regulation probably expected contracting officers to use their judgment and to reward higher risk premiums to contracts where the contractor bears more risk. However, there seems to be no reason not to explicitly state this in the regulations.

Second, as described in Sec. 2, a cost-type contract and a fixed-price-type contract with a sharing rule of γ are not identical. For small increases of cost above expected cost, both contracts will have the contractor bear γ of the overruns. However, at some point specified by the contract (often approximately 120 percent to 140 percent of expected cost), a cost plus incentive (fixed-price incentive) contract reverts to a cost plus fixed fee (firm-fixed-price) contract. Thus, the risk

borne by a contractor under a fixed-price incentive contract with sharing rule γ is greater than the risk borne by a contractor under a cost plus incentive contract with the same sharing rule. The formal analysis of Sec. 4 ignored this nonlinearity of the contract. Thus, it may be that the rule should also be adjusted to reflect this factor, perhaps by adjusting γ up slightly for a fixed-price incentive contract and down slightly for a cost plus incentive contract. The adjustment would be greater when the ceiling is more likely to be breached. It would be straightforward to add this qualitative direction to the regulations. In fact, the previous version of the regulations contained an excellent discussion of this which was omitted in the current version.

C. THE DEPENDENCE OF ω ON ℓ : PART 1

Profit policy formulas do not make either the normal or extreme values of ω depend explicitly on contract length. They do, however, mention contract length in the sections listing qualitative factors that the contract officer should consider when estimating ω . Situations warranting an above-normal value for ω are said to include "long-term contracts without provisions protecting the contractor, particularly when there is considerable economic uncertainty."¹ Situations warranting a below-normal value of ω are said to include "relatively short-term contracts."²

Note, however, that for a given project, increasing the length of time the contractor has to perform the project may substantially reduce the firm's risk because it will have more time to deal with a variety of potential problems that might arise. This fact is also explicitly acknowledged in the regulations. A condition suggesting an above-normal level of risk is said to be "the contractor has accepted an accelerated delivery schedule to meet DoD requirements."³ In another more vague passage, the regulations simply list "delivery schedule"⁴ as a factor that the contracting officer should consider when assessing the level of risk.

Thus, the regulations seem to accept the general principle that on average, longer contracts will be riskier than shorter contracts. Since contract length is an objectively verifiable variable, it would be possible for the regulations to provide more specific guidance regarding

¹48 CFR 215.970-1,b,3,i,A.

²48 CFR 215.970-1,b,3,i,B.

³48 CFR 215.970-1,a,3,i,A.

⁴48 CFR 215.970-1,a,3,i.

this variable. In particular, the suggested average minimum and maximum values of ω could be made explicit functions of ℓ .

This is fundamentally an empirical question. It may be that risk does increase very significantly with contract length for the average contract. In this case it would probably be a good idea to define the normal and extreme values of ω as explicit functions of ℓ . However, it may be that contract length is generally not that determinative of risk levels. Rather, it may be that other factors such as technical complexity and tightness of delivery schedules are the primary determinants of risk. In this case there would be no need to explicitly specify ω as a function of ℓ .

In fact if contract length plays only a small role in determining risk, it may be counterproductive to explicitly specify ω as a function of ℓ . Because the effect of length is objectively specified whereas the effects of other factors are only qualitatively described, contracting officers might focus on the length factor to the exclusion of other factors. If one believed that contract length was one of the most important determinants of risk, this would be fine. However, if one believed that other factors are generally more important, it might be unwise for contract officers to make contract length such an obvious focal point. One particular danger might be that the role of tightness of delivery schedule would be ignored. That is, the same project might tend to be assigned a higher risk premium if the firm is given more time to perform.

Thus, the major point of this subsection is simply to note that an important question that must be explicitly addressed to design the best regulatory policy is "How is the average level of risk affected by contract length and is this a very important effect relative to other factors?" The current policy of not explicitly specifying ω as a function of ℓ is probably correct if the answer to the above question is that contract length is not of major importance in determining risk. However, the policy could probably be improved if this is not the case.

Two possible sources of information could be tapped to resolve this question. First, it would be possible to calculate the standard deviation of actual cost around predicted cost for a large sample of contracts of varying lengths and thus derive a concrete measure of how risk increases with length. It might be possible to determine other characteristics of the contracts, such as technical complexity. In this case, one could attempt to measure which factors explained more of the risk. Second, it is possible that experienced DoD personnel would be able to assess the significance of contract length as a factor influencing risk.

D. THE DEPENDENCE OF ω ON ℓ : PART 2

This subsection summarizes the conclusions of Osband's analysis (1992), which relates to the question of whether ω should be made an explicit function of ℓ . Osband calculates the range of IRRs that results from varying ω between the minimum and maximum allowed values and determines how this range changes with contract length. He shows that the allowed range of IRRs shifts down quite dramatically as length increases so that the lowest allowed IRR for a one-year contract exceeds the highest allowed IRR for a three-year contract. A simple version of this calculation based on the results of Sec. 5 will first be presented. Then the implications of this result for profit policy will be discussed.

1. Calculation of the IRR

These calculations will be presented using periods one-year long so that the interest rates used are annual interest rates.⁵ Consider a contract where delivery occurs ℓ years in the future and all costs are incurred $\ell/2$ years in the future. As in Sec. 5, for simplicity the calculations will be presented for the case where the risk-free rate is assumed to be constant over time and is denoted by R_F . The analysis of Subsection C, Sec. 5, shows that if the pricing rule

$$\pi = \omega \gamma E(\tilde{C}) + \omega(1 - \alpha)F \quad (6.6)$$

is used, the contract's IRR will be determined by

$$(1 + Q)^{\ell/2} = \frac{\gamma\omega}{(1 - \alpha)} + (1 + R_F)^{\ell/2} + \omega[(1 + R_F)^{\ell/2} - 1]. \quad (6.7)$$

As explained in Sec. 5, the IRR yielded by the correct pricing rule depends on all parameters of the situation. Assume that $\gamma = 1$ and $\alpha = 0.8$ (i.e., the contract is FFP with the standard level of progress payments). Also assume that the risk-free rate is 10 percent, which is the long-run average value of the treasury rate calculated in Sec. 2. Then, Eq. (6.7) can be rewritten as

$$Q = \left[4\omega + \omega(1 + R_F)^{\ell/2} + (1.1)^{\ell/2} \right]^{2/\ell} - 1. \quad (6.8)$$

⁵Therefore, uppercase notation for interest rates will be used, denoting that the rates are annual rates.

As explained above, the current regulations probably specify minimum, average, and maximum allowable values of ω by

$$\begin{aligned}\omega_{\text{MIN}} &= 0.0229 \\ \omega_{\text{AV}} &= 0.0370 \\ \omega_{\text{MAX}} &= 0.0510\end{aligned}\quad (6.9)$$

For any fixed contract length ℓ , one can then substitute the three values of ω into Eq. (6.8) to obtain the minimum, average, and maximum allowable IRR. The results of doing this are presented in Table 6.5 and graphed in Fig. 6.1. For reasons explained in Sec. 5, the IRR decreases in ℓ for any fixed value of ω . Thus, the IRR_{MIN} , IRR_{AV} , and IRR_{MAX} will all exhibit the property that they are strictly decreasing in ℓ . They all converge to ∞ as ℓ goes to zero and would all converge to the risk-free rate of 10 percent if ℓ was made large enough.

Notice that the entire range of allowed IRRs shifts down quite dramatically between the lengths of one year to three years. For one year, the lowest allowed IRR is 35.6 percent. For three years, the highest allowed IRR is 26.1 percent.

One could specify ω_{MIN} , ω_{AV} , and ω_{MAX} as functions of ℓ so that the IRR calculated for this example remains constant. Rewrite Eq. (6.8) as

$$\omega = \frac{(1+Q)^{1/2} - (1.1)^{1/2}}{4 + (1.1)^{1/2}} \quad (6.10)$$

Table 6.5

The Minimum, Average, and Maximum IRR as a Function of Contract Length for $\gamma = 1$, $\alpha = 0.8$, and $R_F = 1$ (in percent)

ℓ	IRR_{MIN}	IRR_{AV}	IRR_{MAX}
0	∞	∞	∞
0.5	68.4	114.4	168.7
1.0	35.6	52.7	70.6
1.5	26.1	36.4	46.7
2.0	21.7	28.9	36.0
2.5	19.1	24.6	30.0
3.0	17.4	21.8	26.1
3.5	16.2	19.9	23.4
4.0	15.3	18.4	21.5
4.5	14.6	17.3	20.0
5.0	14.1	16.5	18.8

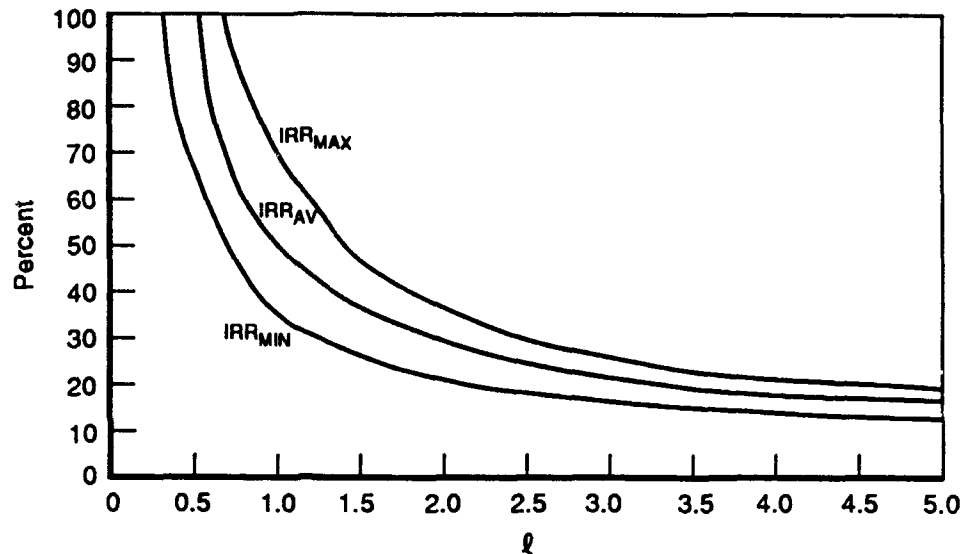


Fig. 6.1—The Minimum, Average, and Maximum IRR as a Function of Contract Length for $\gamma = 1$, $\alpha = 0.8$, and $R_F = 0.1$

Suppose, for example, that we wished the minimum, average, and maximum IRR for the case of $\ell = 2$ to hold true for every length. That is, we wished

$$\begin{aligned} \text{IRR}_{\text{MIN}} &= 0.217 \\ \text{IRR}_{\text{AV}} &= 0.289 \\ \text{IRR}_{\text{MAX}} &= 0.360 \end{aligned} \quad (6.11)$$

to be true for every ℓ . For any fixed contract length ℓ , one can substitute the three values of IRR in Eq. (6.11) into Eq. (6.10) to obtain the required minimum, average, and maximum values of ω . The result of doing this is presented in Table 6.6 and graphed in Fig. 6.2.

All values of ω must converge to zero as ℓ goes to zero for the IRR to remain constant. Furthermore, the growth is relatively dramatic. For example, to produce the same IRR, the risk parameter for a 3.5-year contract must be approximately double that for a two-year contract.

Table 6.6
The Minimum, Average, and Maximum Values of ω Required to
Maintain a Constant IRR
(in percent)

ℓ	ω_{MIN}	ω_{AV}	ω_{MAX}
0	—	—	—
0.5	0.52	0.82	1.11
1.0	1.08	1.71	2.32
1.5	1.67	2.67	3.65
2.0	2.29	3.70	5.10
2.5	2.96	4.82	6.67
3.0	3.66	6.01	8.39
3.5	4.41	7.29	10.25
4.0	5.20	8.67	12.28
4.5	6.04	10.14	14.47
5.0	6.92	11.72	16.85

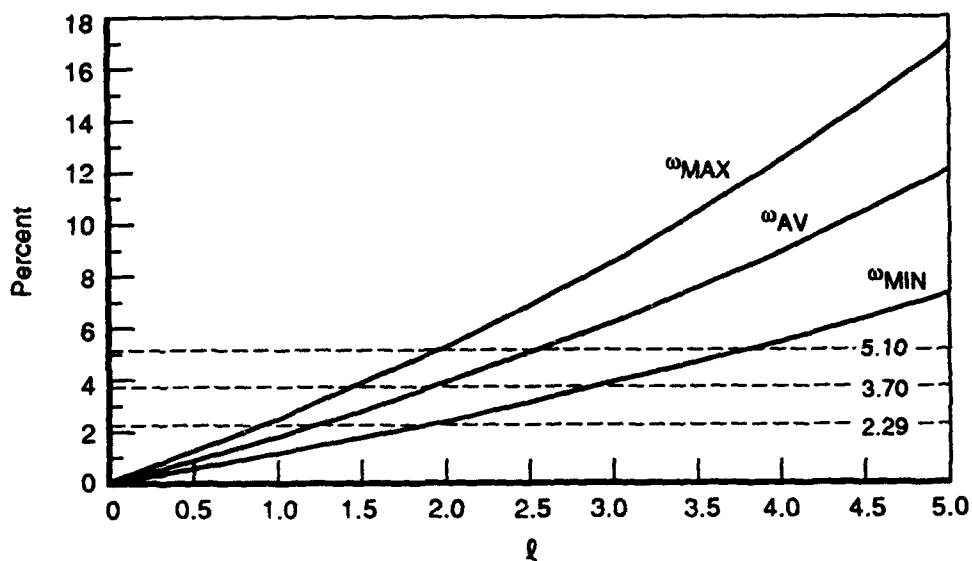


Fig. 6.2—The Minimum, Average, and Maximum Values of ω Required to Maintain a Constant IRR

2. Implications for Profit Policy

The analysis of Sec. 5 clearly demonstrated that the IRR is not a particularly useful number to calculate when evaluating profit rules. The IRR on a correctly priced contract should vary dramatically as

parameters such as α and γ vary. For fixed values of α and γ , the IRR will increase or decrease with contract length depending on how fast risk grows with length. If risk stays constant the IRR should fall. However, it is possible that if risk increases fast enough the IRR should rise. How fast risk increases with contract length for the typical contract is an empirical issue. There is certainly no presumption that the IRR on a correctly priced contract should remain constant.

The fact that demanding that the IRR be constant with length is an arbitrary standard is illustrated by the fact that "constancy of IRR" is a property that depends on γ and α . That is, suppose we believed that for the average contract risk increased just fast enough so that a contract with $\gamma = 1$ and $\alpha = 0.8$ should exhibit a constant IRR when correctly priced. Then, by formula (5.23), we must also believe that if the progress payment rate was raised to 90 percent (lowered to 70 percent) the correctly priced average contract should exhibit an IRR that declines (increases) with contract length. Similarly, we must believe that for contracts with $\gamma < 1$ the IRR should decrease with length. Is it more "natural" to believe that the IRR should be constant when a firm bears 100 percent or 20 percent of the financing cost? The correct answer seems to be that *a priori* there is no "natural" assumption and that the question of whether and to what extent risk increases with length is purely empirical.

Osband's (1992) analysis does show, however, that the question of empirically determining how risk increases with length is an important one. It is conceivable that the correct answer is that the IRR should remain approximately constant. If this were true, Osband's work shows that the correct profit policy rule would be radically different from the current policy. Since the correct policy could vary in extreme ways depending on the empirical behavior of risk, it is important to determine how risk actually does vary with contract length.

7. ESTIMATING THE RISK-FREE RATES

A. INTRODUCTION

Sections 7 and 8 jointly consider the component of profit in the profit policy regulations that calculates the profit meant for the PFC. The CAPM pricing formula for this requires that one estimate the risk-free rates of interest. Section 7 is concerned with how to do this. Then, Sec. 8 conducts the remaining analysis.

B. CONCEPTUAL FOUNDATIONS

The risk-free rates of interest in the CAPM should be interpreted as the rates of return a firm would require on an absolutely risk-free investment. For most firms, a reasonable approximation of this would probably be the rate at which they can borrow short-term funds from banks they have a relationship with. For example, one study of defense contractor financing concluded

[B]anks are the key institutions for financing defense contractors—the only realistic private outside funding source for them, according to virtually all the executives surveyed both within and outside this fraternity. Defense-contractor financing needs are typically oriented toward working capital—to finance inventories and, to a lesser extent, accounts receivable—and fulfilling these needs is the venerable function of banks, which, in line with the character of their obligations, have a relatively short term lending horizon.¹

Therefore, it will be assumed in this report that the correct value for the risk-free rate at time t would be the firm's short-term borrowing cost at time t if this was known at time 0 when the contract is signed. Of course, the future values of these rates cannot be known with certainty. Thus, one must estimate future short-term borrowing rates. This creates two problems. First, one must somehow calculate the expected value of future interest rates. Second, the CAPM assumes that future risk-free rates are known with certainty. If in reality they are uncertain, one should presumably also include some sort of risk premium for the interest rate risk that the firm bears when it signs a contract. Thus, the appropriate size of this risk premium must be somehow determined.

¹Conference Board (1976), p. 5.

Use of the treasury rate probably represents a partial solution to these difficulties because it is supposed to be the rate that firms pay on five-year loans.² A five-year rate will tend to be higher if future short-term rates are expected to rise or if future short-term rates are very uncertain.

This section shows that a much better method exists for determining the risk-free rates. This alternative method employs prices established in futures markets for interest rate instruments that essentially provide market-determined estimates for future expected interest rates and for the appropriate risk premium. Subsection C will describe how these markets work and then Subsection D will describe how the risk-free rates are calculated.

C. THE LONDON INTER-BANK OFFER RATE (LIBOR)

The LIBOR is the interest rate offered on three-month Eurodollar time deposits by major money center banks in Europe.³ According to one recent financial textbook, the "LIBOR is an important benchmark rate, for U.S. banks commonly charge LIBOR plus a certain number of basis points on their floating rate loans."⁴ The LIBOR is thus a good barometer of firms' short-term borrowing costs. A given firm's borrowing rate will probably always tend to be approximately the same number of percentage points above the LIBOR; i.e., if the LIBOR rises three percentage points, so will the firm's borrowing costs.

The prime rate is another indicator of firms' short-term borrowing costs. These two rates are, of course, highly correlated. Table 7.1 presents a time series for both of these rates at six-month intervals since 1980 when the LIBOR began to be published. For future reference, the treasury rate for the same time periods is also presented. A linear regression of the LIBOR on the prime rate yields an R^2 of 0.98. The average values in Table 7.1 show that the prime averages 1.4 percentage points above the LIBOR. Thus, it is essentially the case

²Recall from Sec. 2 that the legislative directions to the Treasury Department instruct it to measure a five-year rate. Regression analysis confirmed that the treasury rate was more closely correlated with the five-year government bond rate than the short-term bond rate.

³LIBORs for deposits of other maturities also exist. However, futures contracts are written solely on the three-month LIBOR. Therefore, the three-month rate is the one of interest for this report.

⁴Siegel and Siegel (1990).

Table 7.1
The LIBOR, Prime Rate, and Treasury Rate
(in percent)

Date	LIBOR ^a	Prime Rate ^b	Treasury Rate ^b
July 1980	9.8125	11.48	10.500
January 1981	17.8750	20.16	14.625
July 1981	17.8125	20.39	14.875
January 1982	13.8750	15.75	14.750
July 1982	16.000	16.26	15.500
January 1983	9.3125	11.16	11.250
July 1983	9.8125	10.50	11.500
January 1984	9.9375	11.00	12.375
July 1984	12.2500	13.00	14.375
January 1985	8.6875	10.61	12.125
July 1985	7.9375	9.50	10.375
January 1986	8.000	9.50	9.750
July 1986	6.8750	8.16	8.500
January 1987	6.4375	7.50	7.625
July 1987	7.1875	8.258	8.875
Average	10.8	12.2	11.8

^aThis is the three-month LIBOR on the first business day of the month as published in the *Wall Street Journal*.

^bFrom Table 2.1.

that the prime and LIBOR move up and down almost perfectly together with the LIBOR 1.4 percentage points below the prime.

The current value of the LIBOR therefore provides essentially the same information as the current value of the prime rate. The former is essentially 1.4 percentage points below the latter. One could thus predict a firm's short-term borrowing cost from either rate so long as one knew the typical spread between the firm's rate and the LIBOR or prime. The key reason that the LIBOR is of greater interest than the prime for the purposes of this report is that a well-organized futures market exists for the LIBOR. It will be shown below that this essentially allows one to use market-determined estimates for the future value of interest rates.

Now, a brief stylized description of how the LIBOR futures market operates is presented.⁵ Some notation will be useful to describe the operation of the market. Since the LIBOR rate is for a three-month deposit and futures markets exist for the LIBOR at three-month in-

⁵Some of the details of the following description have been changed slightly to facilitate exposition. See Siegel and Siegel (1990) for a complete description.

tervals into the future, it is convenient to think of time unfolding in a discrete number of three-month periods. Let period 0 denote the current period. Let period t for positive integer values of t denote the period beginning $3t$ months in the future. Let L_t denote the annualized value of the LIBOR in period t .⁶ In the current period only L_0 is known. The future values of L_t will become known in period t . The futures market in the current period establishes futures rates for future periods. Let \hat{L}_t denote the futures rate for period t .⁷ These futures rates can be thought of as the market's guess as to the future value of L_t .

By "going long" x dollars on period t futures, an investor will receive

$$x[L_t - \hat{L}_t]/4 \quad (7.1)$$

at the end of period t . (If this value is negative the investor loses money.) By "going short" x dollars on period t futures, an investor will receive

$$x[\hat{L}_t - L_t]/4 \quad (7.2)$$

at the end of period t .

The LIBOR futures market essentially allows firms to lock in the interest rate they will pay on future borrowings so long as their borrowing rate is closely correlated with the LIBOR and so long as they know the amount they want to borrow. This will now be explained. Suppose that a firm knows that it will have to borrow x dollars during period t . Suppose that it also knows that if it waits to borrow the money until then it will borrow at the then-current LIBOR plus k . The firm can use the LIBOR futures market to "lock in" a rate equal to $\hat{L}_t + k$ if it desires. It does this by going long x dollars. Then at time t it borrows x dollars and pays interest of

$$x[\hat{L}_t + k]/4 \quad (7.3)$$

at the end of period t . However, it receives

⁶That is, a person who invested x dollars at the beginning of period t in a bank offering the LIBOR would receive $x[1 + L_t/4]$ dollars back at the end of three months.

⁷Currently, LIBOR futures rates exist 12 periods into the future.

$$x[L_t - \hat{L}_t]/4 \quad (7.4)$$

from the futures contract. The net payment of the firm is given by Eq. (7.3) minus Eq. (7.4), which equals

$$x[\hat{L}_t + k]/4 . \quad (7.5)$$

This is the interest the firm would pay if it had received a loan at the rate $\hat{L}_t + k$.

This result can be summarized as follows. Let δ_t denote the difference between the period t futures rate and the current LIBOR.

$$\delta_t = \hat{L}_t - L_0 . \quad (7.6)$$

The vector of δ_t 's is often referred to as the term structure of the LIBOR. Let B_t denote the firm's annualized borrowing rate in period t , which is by assumption given by

$$B_t = L_t + k . \quad (7.7)$$

Then in period 0 the firm can choose to lock in a rate equal to

$$B_0 + \delta_t \quad (7.8)$$

to borrow money during period t . Thus, the difference between the LIBOR futures rates and the current LIBOR also determines the differences between the firm's current borrowing cost and the rates it can lock in for the future.

D. ESTIMATING THE RISK-FREE RATES

It was established above that the risk-free rates should be set equal to the firm's future short-term borrowing rates if these were known with certainty at the time of contracting. The problem with implementing this conceptual rule was that these futures rates are not known at the time of contracting. Subsection C showed that the LIBOR futures market essentially allows firms to lock in the rates at which future short-term borrowings will occur. Thus, this supplies the solution to implementing the conceptual rule of Subsection B. The rates that firms can lock in through use of the LIBOR should be used as the

risk-free rates. One can interpret these futures rates as being the risk-adjusted expected value of future interest rates.

Specifically, then, the suggested method is as follows. First, the premium above the current LIBOR paid by a typical defense firm must be determined, perhaps by conducting a survey. Suppose that this is found to be the value k .⁸ That is, the annualized borrowing rate for a typical defense firm in period t will be

$$B_t = L_t + k . \quad (7.9)$$

Subsection C showed that at time 0 the firm can actually lock in a rate of

$$B_0 + \delta_t \quad (7.10)$$

for its period t borrowings. Let R_F^t denote the annualized period t risk-free rate.⁹ Since at time 0 the firm can literally obtain the rate in Eq. (7.10) for its period t borrowings, the appropriate risk-free rate is given by

$$R_F^t = B_0 + \delta_t \quad (7.11)$$

or, equivalently, by

$$R_F^t = L_0 + k + \delta_t \quad (7.12)$$

or

$$R_F^t = \hat{L}_t + k . \quad (7.13)$$

Note that this method is theoretically perfect only if the firm's borrowing costs are perfectly correlated with the LIBOR and if the firm

⁸It is probably the case that the value of k varies between defense firms. Large, solvent, highly successful firms will have lower borrowing costs than smaller or financially troubled firms. The current regulations use the same interest rate for all firms. Presumably, this gives firms maximum incentive to arrange their affairs to minimize their borrowing rate. Whether it would be optimal to actually have different interest rates used for different firms is an incentive issue beyond the scope of this report. Thus, it will be assumed that a single value of k equal to the value for a typical defense firm is used to determine the risk-free rates for all firms. Obviously this scheme could be modified to use firm-specific values of k if this was thought to be optimal.

⁹Recall that this is given by $R_F^t = 4r_F^t$, since periods are three months long.

knows with certainty the amount of money it will need to borrow in each period. Neither condition is perfectly met in reality. Borrowing costs probably do not move in exact synchronization with the LIBOR. More important, the cost of production is uncertain and thus the exact amount of money required for contract financing each period is not known. Thus, the use of formulas (7.11) – (7.13) is not theoretically perfect. However, it seems to provide a very practical and easy method for estimating future interest rates and at least a partial risk premium.

E. A TIME-INVARIANT RISK-FREE RATE

1. Introduction

The method proposed above yields risk-free rates that differ across time periods. Although theoretically correct, this is more cumbersome than simply publishing a single time-invariant risk-free rate. This subsection investigates whether significant distortions would be created by publishing a single "average" risk-free rate rather than a vector of time-varying rates. The discussion below shows how to theoretically calculate such a rate and also shows that the error created by using such an average rate would be quite small.

2. Theory

For any pattern of cost incurrence and set of risk-free rates, one can calculate a single interest rate that would yield the same financing cost. This will be called the time-invariant discount rate for a given set of expected costs and risk-free rates.

Consider a contract with expected cash flows

$$\left\{ E(\tilde{C}_t) \right\}_{t=1}^n \quad (7.14)$$

For a given set of risk-free rates

$$\left\{ r_F^t \right\}_{t=1}^n$$

one can calculate the risk-free financing cost, F , according to Eq. (4.11). A single time-invariant value exists for the risk-free rate, r_F , which would produce the same value of F . This is determined by the formula

$$\sum_{t=1}^n E(\tilde{C}_t) \hat{z}(t) = \sum_{t=1}^n E(\tilde{C}_t) z(t) , \quad (7.15)$$

where

$$\hat{z}(t) = (1 + r_F)^{(n+1-t)} - 1 \quad (7.16)$$

and

$$z(t) = \left[\prod_{i=t}^n (1 + r_F^i) \right] - 1 . \quad (7.17)$$

Since the left-hand side of Eq. (7.15) is monotone strictly increasing and varies between 0 and ∞ , there exists a unique solution to Eq. (7.15). However, it is not possible to solve for it in closed form. Therefore, an approximation of r_F will be solved for instead by calculating F using simple interest. This amounts to replacing Eqs. (7.16) and (7.17) by

$$\hat{z}(t) = r_F(n+1-t) \quad (7.18)$$

and

$$z(t) = \sum_{i=t}^n r_F^i . \quad (7.19)$$

This will be called the approximate time-invariant rate.

Definition:

The time-invariant discount rate (approximate time-invariant discount rate) given

$$\left\{ E(\tilde{C}_t) \right\}_{t=1}^n$$

and

$$\left(r_F^t \right)_{t=1}^n$$

is the solution to r_F of Eqs. (7.15) – (7.17) (Eqs. (7.15), (7.18), and (7.19)).

The following notation will be useful to present the result. Let E^t denote the cumulative expected costs up to period t .

$$E^t = \sum_{i=1}^t E(\tilde{C}_i) . \quad (7.20)$$

Define a set of nonnegative weights that sum to one by

$$s_t = \frac{E^t}{\sum_{i=1}^n E^i} . \quad (7.21)$$

Proposition 4 now presents the results.

Proposition 4:

The approximate time-invariant discount rate given

$$\left\{ E(\tilde{C}_t) \right\}_{t=1}^n$$

and

$$\left\{ r_F^t \right\}_{t=1}^n$$

is given by

$$r_F = \sum_{t=1}^n s_t r_F^t \quad (7.22)$$

or equivalently, in terms of annualized rates, by

$$R_F = \sum_{t=1}^n s_t R_F^t . \quad (7.23)$$

Proof:

Substitute Eqs. (7.18) and (7.19) into Eq. (7.15) and reorganize. Q.E.D.

Note that the weights

$$\{s_t\}_{t=1}^n$$

are monotonically increasing in t . Thus, the approximate time-invariant discount rate is a weighted average of the risk-free rates with more weight being placed on the risk-free rates from later periods. There is a very intuitive reason for this. More costs have been incurred by later periods and thus the risk-free rates of later periods are applied to a greater fraction of the costs.

A particularly simple case occurs when costs are uniformly incurred; i.e., $E(\tilde{C}_t)$ is constant for every period. Then, the weights are given by

$$S_t = \frac{t}{\sum_{i=1}^n i} . \quad (7.24)$$

It will be useful to view Eq. (7.23) in a slightly different fashion. Define Δ to be the amount by which R_F exceeds the firm's current borrowing cost.

$$\Delta = R_F - L_0 - k . \quad (7.25)$$

Then substitution of Eqs. (7.25) and (7.12) into Eq. (7.23) yields

$$\Delta = \sum_{t=1}^l s_t \delta_t . \quad (7.26)$$

Thus, the extent to which the time-invariant discount rate exceeds the firm's current borrowing cost is equal to a weighted sum of the δ_t parameters.

3. The Error from Using a Time-Invariant Risk-Free Rate

Two factors affect the term structure of the LIBOR. Because of interest-rate risk, the LIBOR futures rates tend to rise over time. (A firm

must pay a premium to guarantee that it will be able to borrow at a fixed rate in some future time period.) This underlying rising trend will be strengthened or diminished depending on whether the market expects the LIBOR to rise or fall. It is quite rare for expectations of falling rates to be so strong that the LIBOR futures rates actually fall. Thus, the LIBOR futures rates will typically rise for periods further in the future. In terms of the δ_t parameters, this means that they will typically be positive and increasing.

Therefore, according to formula (7.26), the correct time-invariant interest rate for a given contract will typically be higher if

- (i) The contract is longer.
- (ii) A greater fraction of the costs are incurred in later periods.

In particular, it is impossible to announce a single time-invariant risk-free rate that is precisely correct for all contracts. Thus, if the regulations were to specify a single time-invariant rate, the best that could be done would be to specify a rate that was exactly correct for a contract of typical length with a typical pattern of cost incurrence. The regulations would then overcompensate shorter contracts and contracts where more cost was incurred in earlier periods and undercompensate longer contracts and contracts where more cost was incurred in later periods.

The purpose of this subsection is to roughly quantify the size of this error. The size of the error, of course, depends on how fast the δ_t parameters increase. If δ_t is constant then it is perfectly correct to use a time-invariant rate and there is no error. However, as δ_t increases more rapidly, then so should the risk-free rates and the error from using a constant rate increases.

Appendix G statistically analyzes historical values of the LIBOR futures rates to develop three different sets of values for the δ_t parameters. These are presented in Table G.4. The set $\{\delta_t^*\}$ will be called the *typical values*. These are averages of the historical values. The set $\{\bar{\delta}_t\}$ will be called the *extreme increasing values*. These represent values that exhibit the most extreme increase in t that we are likely to see in a ten- to fifteen-year period. The set $\{\underline{\delta}_t\}$ will be called the *extreme decreasing values*. These represent values that exhibit the most extreme decrease in t that we are likely to see in a 10- to 15-year period.

With reference to Table G.4, notice that the typical values are positive and increasing as suggested above. The extreme increasing values

are larger and increase more quickly. The extreme decreasing values are actually negative and decreasing. This is referred to as an inverted term structure, since futures rates are actually decreasing for periods further in the future. Such a situation is quite rare, however, and note that the rate of decrease is quite small. That is, the maximum decreasing values are actually only mildly decreasing and are all very close to zero.

This subsection will calculate the error from using a single time-invariant interest rate for the three sets of values of δ_t described above. The error under δ_t^* can be interpreted as the typical error. The error under $\bar{\delta}_t$ can be interpreted as the largest error that would occur in a 10- to 15-year time period. Note that the errors under $\underline{\delta}_t$ will be of reversed sign to those under δ_t^* and $\bar{\delta}_t$. However, since $\underline{\delta}_t$ is nearly constant, the errors will be quite small in absolute value. For completeness they will be presented but the errors calculated for the other two cases are more relevant for assessing the typical and maximum plausible errors.

Two calculations will be performed to estimate the size of these errors. It will be assumed for both calculations that the regulations use a time-invariant rate determined by calculating the rate that would be correct for a three-year contract when costs are expected to be uniformly incurred. Then, first the error that results from using this rate on contracts of differing lengths (maintaining the assumption of uniform expected cost incurrence) will be calculated. Second, the error that results from using this rate when all costs are expected to be incurred in a single period (maintaining the assumption of a three-year length) will be calculated. Only the results will be presented. All supporting calculations can be found in App. H.

First, consider variations in contract length. Let $\varepsilon(n, 12)$ denote the error as a percentage of expected cost in the payment of working capital profit when a time-invariant rate is used for a three-year contract with uniform cost incurrence but the contract is actually n periods long (with uniform cost incurrence).¹⁰ Values of $\varepsilon(n, 12)$ are presented in Table 7.2. The columns labeled $\underline{\varepsilon}(n, 12)$, $\varepsilon^*(n, 12)$, and $\bar{\varepsilon}(n, 12)$ present values of $\varepsilon(n, 12)$ calculated using, respectively, $\underline{\delta}_t$, δ_t^* , and $\bar{\delta}_t$. Note that all errors (expressed as a percentage of expected cost) are quite small. The largest error is -0.28 percent. That is, for a five-year contract when futures rates are at their extreme increasing

¹⁰This seemingly awkward notation is chosen to be consistent with the derivation in App. H where the notation is required. Recall that periods are 3 months long.

Table 7.2

The Value of $\varepsilon(n, 12)$
(in percent)

n	Length in Years (ℓ)	$\underline{\varepsilon}(n, 12)$	$\varepsilon^*(n, 12)$	$\bar{\varepsilon}(n, 12)$
1	1/4	-0.01	0.03	0.07
2	1/2	-0.02	0.06	0.12
3	3/4	-0.02	0.07	0.15
4	1	-0.03	0.08	0.17
5	1-1/4	-0.03	0.09	0.18
6	1-1/2	-0.03	0.08	0.17
7	1-3/4	-0.02	0.08	0.16
8	2	-0.02	0.07	0.14
9	2-1/4	-0.02	0.05	0.11
10	2-1/2	-0.01	0.04	0.08
11	2-3/4	-0.01	0.02	0.04
12	3	0.0	0.0	0.0
13	3-1/4	0.01	-0.02	-0.04
14	3-1/2	0.01	-0.04	-0.08
15	3-3/4	0.02	-0.06	-0.11
16	4	0.02	-0.07	-0.15
17	4-1/4	0.03	-0.09	-0.18
18	4-1/2	0.04	-0.10	-0.21
19	4-3/4	0.04	-0.12	-0.24
20	5	0.05	-0.13	-0.28

values, the contract would receive a profit 0.28 percent less than the correct amount. If we restrict ourselves to the more plausible case of contracts lasting four years or less, the largest possible error shrinks to -0.15 percent of expected cost. It seems reasonable to assume that errors of this magnitude will be relatively insignificant given estimating uncertainties.

Now consider variations in the pattern of cost incurrence. As before, assume that the correct time-invariant rate for a contract lasting three years with uniform cost incurrence is used. However, assume that 100 percent of costs are actually incurred in period t although delivery and payment does not occur until period 12 (three years after the start). Let $\varepsilon(t)$ denote the error in profit paid to the firm as a percentage of expected cost from doing this. Table 7.3 presents the values of $\varepsilon(t)$ (once again, for the three possible sets of values of δ_t). Although somewhat larger, all errors are still less than one-half of one percent of expected cost. Furthermore, the cases being considered where literally all costs are incurred in a single period are quite extreme. Less-extreme deviations from uniform cost incurrence would generate even smaller errors.

Table 7.3
The Value of $\varepsilon(t)$
(in percent)

t	$\underline{\varepsilon}(t)$	$\varepsilon^*(t)$	$\bar{\varepsilon}(t)$
1	0.0	0.01	0.03
2	-0.01	0.02	0.04
3	0.0	0.01	0.03
4	0.0	0.0	0.01
5	0.01	-0.01	-0.03
6	0.01	-0.03	-0.07
7	0.02	-0.06	-0.13
8	0.03	-0.09	-0.19
9	0.04	-0.13	-0.26
10	0.05	-0.17	-0.34
11	0.07	-0.21	-0.43
12	0.08	-0.25	-0.52

Therefore, the errors created by using the time-invariant rate for a three-year contract with uniform cost incurrence for all contracts regardless of their length or pattern of cost incurrence appear to be very small. Even in extreme cases, they are less than one-half of one percent of expected cost and typically they would be closer to one-tenth of one percent of expected cost. Therefore, it appears that it would be reasonable for the regulations to use a single time-invariant rate to simplify their application. This will be the procedure recommended as part of the proposed revision.

F. SUMMARY OF THE PROPOSED METHOD

To describe the proposed method, two assumptions will be made. However, as will be explained, they could be changed. First, it will be assumed that a new rate is announced every six months as is currently done. However, since all calculations in the proposed scheme are automatic, one could easily imagine a new rate being announced more often. Second, it will be assumed that the announced rate is the time-invariant rate for a three-year contract with uniform cost incurrence. Obviously, a different length or time pattern of cost incurrence could be used if desired.

The proposed method is then as follows. First, a survey must be conducted to determine how a typical defense firm's short-term borrowing rate compares with the LIBOR. This will determine k . This value

is determined once and for all and is not recalculated every six months.¹¹

Then, every six months a new risk-free rate would be calculated as follows. On the day before the announcement, the LIBOR futures rates for that day would be determined. Let \hat{L}_t denote the LIBOR futures rate t quarters in the future. Then, the annualized risk-free rate would be given by

$$R_F = k + \sum_{t=1}^{12} s_t \hat{L}_t, \quad (7.27)$$

where

$$s_t = \frac{t}{\sum_{i=1}^{12} i}. \quad (7.28)$$

The final question that needs to be addressed is who should calculate the risk-free rate. Notice that the calculation is perfectly mechanistic and could simply be described in a regulation, given the value of k . Therefore, the DoD could easily assign the biannual calculation of the risk-free rate given k to some administrative group within the DoD. The real question is who should be assigned the responsibility for calculating k .

A good argument can be made for assigning this responsibility to some group outside the DoD as is now the case with calculation of the treasury rate. This removes the temptation for the DoD to artificially lower or raise k to achieve its own bureaucratic aims. For example, in a time of very tight budgets, the Secretary of Defense might be tempted to pressure his subordinates to recalculate k to be a lower number. Perhaps the GAO or the Treasury Department would be the ideal group to be assigned responsibility for this calculation. New legislation would be created instructing the chosen group to calculate the value of k . Perhaps it could be called the "cost of funds premium." The legislation would define k to be the premium above the current LIBOR that typical defense firms have paid for their short-term borrowing over the last five years. The legislation would also instruct

¹¹Of course, over the long run it may be that k changes and one could imagine that the DoD might redetermine its value every five years or so. The point being made here is that it is *not* reset every six months.

the group to periodically review the value of k , perhaps every few years.

G. ADVANTAGES OF THE PROPOSED METHOD

The main advantage of the proposed method is that it provides a theoretically correct method to use objective market-determined values to determine the expected values of future interest rates and the appropriate risk premiums for interest rate risk. The only number that is not totally objectively verifiable in the proposed method is k , the amount that the typical defense firm pays above the LIBOR for its short-term borrowing. However, this could be easily and accurately estimated by conducting a survey. As explained in Subsection B, the treasury rate probably provides a somewhat accurate reflection of these factors, since it is supposed to be a five-year rate. However, the proposed method provides an exact measure of precisely the factors that need to be measured.

To quantify whether the proposed method would provide significant increases in accuracy, the correct experiment to perform would be to actually estimate k , obtain LIBOR futures rates for all periods since 1971, calculate the interest rates that the proposed method would have yielded over this period, and compare these rates to the treasury rates that actually were used. The two sets of rates could differ in two ways.

1. The average levels over time could be different.
2. The rates might not move up and down together through time.

Since the proposed method is theoretically correct, the existence of large differences of either sort would provide evidence that the proposed method would significantly improve accuracy.

Unfortunately, as explained above, this analysis cannot be done because the LIBOR futures market is relatively new. It has been in existence only since 1982 and futures rates three years into the future have existed only since 1987. Furthermore, it is beyond the scope of this report to conduct a survey to determine k .

However, a more limited investigation of accuracy of the type described in (1) above can be conducted with the available data. That is, whether the treasury rate has on average been too high or too low can be investigated. Suppose that the typical values of differences between LIBOR futures rates and the current LIBOR are equal to $\{\delta_i^*\}$ from Table G.4. Also suppose that the time pattern of cost incurrence

is approximately uniform and that the typical contract lasts approximately three years. Then, substitution of the values of $\{\delta_t^*\}$, Eq. (7.24), and Eq. (7.26) into Eq. (7.25) shows that the risk-free rate should satisfy the following relationship in a typical period:

$$R_F = L_0 + k + 0.0147 . \quad (7.29)$$

In particular, the correct risk-free rate should average $k + 0.0147$ above the LIBOR. Table 7.1 shows that the treasury rate has averaged 0.01 above the LIBOR since 1980. Thus, for the treasury rate's average level since 1980 to be correct, it must be the case that $k = -0.0047$. That is, it must be the case that firms can borrow at a rate 0.47 percentage points below the LIBOR. Since the LIBOR averaged 1.4 percentage points below the prime in this same period, this is equivalent to saying that firms can borrow at a rate 1.87 percentage points below the prime.

As stated above, it is beyond the scope of this report to determine the value of k . However, it seems very likely that k exceeds zero. In fact, *a priori*, it might be reasonable to guess that firms' current borrowing occurs at the prime. If this is true, then $k = 0.014$. In this case, the average level of the treasury rate has been 1.87 percentage points too low since 1980!

The above is just speculation, of course. However, the point to notice is that the theory of this section has transformed a poorly defined question for which no unambiguous answer seemed possible (i.e., Is the treasury rate too high or too low?) into a very precise question that in principle is easy to empirically answer (i.e., What is the value of k ?).

To assess the impact of the proposed revision of profit policy regulations, it will be assumed in subsequent sections that the new method for calculating the risk-free rate would produce a rate averaging 1-1/2 percent above the treasury rate.

8. PROFIT FOR WORKING CAPITAL

A. INTRODUCTION

This section identifies the component of profit in profit policy regulations meant to be profit for the PFC, which will also be called the profit for working capital. It analyzes how the calculation should be changed in light of the theory. Recall that Sec. 4 suggests that the correct rule should have the form

$$\pi_{PFC} = (1 + \omega)(1 - \alpha)F, \quad (8.1)$$

where ω is the same risk premium used for the PPC. The analysis in Sec. 7 showed that very little error would be created by using a single time-invariant risk-free rate to calculate F . This section will therefore assume that a single time-invariant risk-free rate denoted by R_F exists and is correctly calculated. It will then analyze whether the current rule is correct if the correct risk-free rate was used instead of the treasury rate in the current formula and how the rule should be changed if it is not correct.

Since the current regulations specify different rules for the three cases of cost-type contracts, fixed-price-type contracts with no progress payments, and fixed-price-type contracts with progress payments, these are each considered in turn in Subsections B, C, and D. Then, Subsection E describes how the calculation of profit for working capital can be integrated with existing calculations of flexible progress payment rates under the Cash IV program. Finally, Subsection F comments on the historical practice of using the progress payment rate as a policy tool to affect economic profit levels in the defense industry and the effects of the proposed revision on this practice.

B. COST-TYPE CONTRACTS

These contracts receive progress payments of 100 percent. Since F equals 0 in this case, the optimal rule in Eq. (8.1) agrees with the actual rule. Both say to give no return to working capital because none is used.

C. FIXED-PRICE-TYPE CONTRACTS WITH NO PROGRESS PAYMENTS

The actual rule in this case gives a profit of 1.76 percent of total cost. Before the latest revision of profit regulations in 1987, all returns to working capital were simply calculated as a fixed percentage of expected costs. In particular, no attempt was made to adjust for the length of the contract or the level of interest rates. Thus, longer-than-average (shorter-than-average) contracts received a lower (higher) rate of return on working capital. Similarly, in times of high interest rates (low interest rates) all contractors were worse (better) off. A major conceptual change in the latest revision of profit policy was to explicitly calculate a return to working capital based on contract length and the level of interest rates. This formula is used for calculating a return to working capital when progress payments are given and will be discussed in Subsection D below. As will be seen, it is not perfect. Nonetheless, it certainly makes some allowance for contract length and interest rates and thus represents a major step forward.

For some inexplicable reason, drafters of the new regulations did not change the approach used for calculating a return to working capital when no progress payments are given. In one sense, this is the more important case, since the amount of working capital used will be much greater. Fortunately, in another sense it is not so important, since major contracts receive progress payments. Certainly, however, the regulations should be changed so that a profit for working capital when no progress payments are given is calculated by the same formula as is used when progress payments are given. The parameter, α , representing the level of progress payments, would simply be set equal to 0 for the case of no progress payments.

D. FIXED-PRICE CONTRACTS WITH PROGRESS PAYMENTS

The correct rule for calculating the cost of working capital is given by Eq. (8.1). It consists of a risk premium, $(1 + \omega)$, multiplied by the share of contractor supplied financing, $(1 - \alpha)$, multiplied by the risk-neutral financing cost F . The actual rule is given by

$$\pi = (1 - \alpha) \{ R_F L(\ell) E(\tilde{C}) \} . \quad (8.2)$$

As explained in the introduction, it will be assumed that the regulations use the correct risk-free rate in place of the treasury rate.

Recall that the length factor is essentially a ray from the origin with slope 1/2 shifted down by 0.35 and with a floor and ceiling.

$$L(\ell) = \begin{cases} 0.4 & , \ell \leq 1.5 \\ -0.35 + 0.5\ell & , 1.5 \leq \ell \leq 6.5 \\ 2.9 & , \ell \geq 6.5 \end{cases} \quad (8.3)$$

To compare the rules in Eqs. (8.1) and (8.2), the procedure is to compare the analogous component in Eq. (8.2) to each of the three components in Eq. (8.1). First, consider the risk premium $(1 + \omega)$. The actual rule obviously contains no risk premium. Thus, this should be corrected. The correct rule should instruct the contracting officer to apply the same risk premium to the working capital calculation as was used for the contract risk calculation.

Note, however, that this connection will not result in a particularly significant difference given the current values of ω allowed for in the regulations. Recall from Sec. 6 that the regulations specify a normal value for ω of 0.037 and a range of 0.0227 to 0.0510. As a rough magnitude, the value of F can be approximated by

$$F = R_F \frac{\ell}{2} E(\tilde{C}) \quad (8.4)$$

as explained in App. D. Substitution of Eq. (8.4) into Eq. (8.1) yields

$$\pi_{PFC} = (1 + \omega)(1 - \alpha)R_F \frac{\ell}{2} E(\tilde{C}) \quad (8.5)$$

For $\alpha = 0.8$, $R_F = 0.16$, and $\ell = 5$, this becomes¹

$$\pi_{PFC} = 0.08(1 + \omega)E(\tilde{C}) \quad (8.6)$$

Therefore, including ω increases profit by $0.08\omega \times 100$ percent of expected cost. This results in increases of 0.18 percent, 0.3 percent, and 0.4 percent of expected costs for the minimum, typical, and maximum values of ω . None of these are extremely significant.

Thus, the analysis of this report together with the implied estimates of ω embedded in the current regulations suggest that the cost of

¹The largest plausible values for R_F and ℓ are chosen to obtain an upper bound on the effect of including ω .

capital is fairly close to the risk-free cost. In particular, the current regulations' practice of not including a risk premium does not create significant error.

This raises the issue of whether the regulations should be modified to include a risk premium. The important point here is that it is essentially costless to modify the regulations to include the premium, since it must already be calculated as part of the PFC calculation. Thus, even relatively modest gains in accuracy provide sufficient reason to include the parameter. Although 0.3 percent of expected costs may not be an extremely large value, it does represent \$3 million on a \$1 billion contract. Therefore, because it is essentially costless to implement, the regulation probably should include the risk premium.

Now consider the second component of Eq. (8.1) given by $(1 - \alpha)$. The actual rule also multiplies by $(1 - \alpha)$, so there is no discrepancy.

Finally, consider the third component of Eq. (8.1) given by F . The analogue in Eq. (8.2) is the term in brackets given by

$$\hat{F} = R_F L(\ell) E(\tilde{C}) . \quad (8.7)$$

Therefore, the existing regulation can be viewed as calculating the risk-free financing cost for a contract by using the formula in Eq. (8.7). The correct value of F is, of course, defined by

$$F = \sum_{t=1}^T E(\tilde{C}_t) \left\{ (1 + R_F)^{T+1-t} - 1 \right\} . \quad (8.8)$$

The first point to notice about Eq. (8.7) is that it could not possibly be perfectly correct for all possible contracts because it does not explicitly depend on the time pattern of cost incurrence. That is, \hat{F} depends only on the length of the contract and the magnitude of total costs. Thus, according to Eq. (8.7), a 10-year contract that involved spending \$1 million in year 1 and nothing thereafter would have the same financing cost as a 10-year contract that involved spending \$1 million in year 10 and nothing before. Obviously, this is not true. The time pattern of cost incurrence can significantly affect the value of F .

The motivation of the drafters of the regulation must have been to reduce calculational complexity. To use Eq. (8.8), a contracting officer must both

- (i) Estimate expected cost incurrence by period (where periods would probably be monthly).
- (ii) Understand how to calculate compound interest.

Obviously formula (8.7) places lower demands on the contracting officer. He must only know total expected cost and be able to multiply.

An optimal regulatory policy would presumably attempt to trade off perfect accuracy against excessive complexity and calculational and informational requirements. However, it seems clear that the current regulations have probably failed to properly do this in two major respects. These will now be described.

First, for major contracts there is absolutely no difficulty in performing the correct calculation. The contracting officer will already have calculated estimates of expected cost broken down by month. All contracting officers are able to calculate compound interest. Therefore, significant gains in accuracy can be achieved at zero cost and there seems to be no reason that these gains should not be achieved. Therefore, at a minimum the regulations should specify the perfectly correct rule as well as the simple rule. The regulations would then specify that a contracting officer could always choose to use the correct rule² and would also specify conditions under which the correct rule must be used. Perhaps crossing above a minimum dollar or length threshold should trigger mandatory application of the correct rule. Furthermore, it may be that the regulations do not have to specify a mathematical formula. Rather, they could simply reference a computer program for calculating F , which is then made available to contracting officers. This will be further discussed in Subsection E.

Second, even if a "simple" formula depending only on ℓ and $E(\bar{C})$ should be included for use on small contracts, the current version in Eq. (8.7) is probably not the right one to use. The correct procedure for calculating a simple rule would be to first establish the nature of the typical pattern of cost incurrence. Then, a formula for F as a function of ℓ and $E(\bar{C})$ could be created under the assumption that cost incurrence followed this pattern.

Therefore, in evaluating whether Eq. (8.7) is a correct formula, we need to determine if it corresponds to an estimate of F given some plausible pattern of cost incurrence. A number of reasons suggest

²Perhaps it would also be useful to give contracting firms the right to ask that the correct formula be used if they were willing to supply the required data on the time pattern of cost incurrence.

that this is not the case. First, the length factor is constant at 0.4 for all values of $\ell < 1.5$. This will clearly overcompensate contracts of very short duration. Second, the same point applies to the fact that the length factor is constant at 2.9 for all contracts of length greater than 6.5. Since almost no contracts run this long, the damage done by not allowing $L(\ell)$ to increase with ℓ beyond 6.5 is probably minimal. Third, the traditional approach of the DoD procurement community has been to assume that $L(\ell)$ equals $\ell/2$. This was the approach used by the last major DoD study of profit policy (DoD, 1985a), for example. The current regulations maintain the slope of 0.5 of the traditional DoD approach. Probably, the genesis of the current regulation was simply to begin with the traditional approach and lower it by 0.35 because it seemed a bit high. This resulted in negative values of $L(\ell)$ for low values of ℓ so an arbitrary floor was set of 0.4. Thus, although it is possible that a great deal of analysis went into empirically estimating a typical pattern of cost incurrence and using it to estimate $L(\ell)$, this appears unlikely.

Appendix D shows that there is a fairly reasonable justification for using the length factor $\ell/2$ to determine a simple rule. This formula is a very good approximation to F for the case where cost incurrence is uniform. Therefore, in the absence of any other information, it seems that past DoD practice together with this theoretical justification suggests that a length factor of $\ell/2$ would be appropriate for the simple rule. Note, however, that more empirical investigation should clearly be conducted to verify if uniform cost incurrence is a reasonable assumption.

E. THE CASH IV PROGRAM

For notational simplicity, all the calculations of this report have been carried out under the assumption that there are no floats or lags. A float occurs when the firm receives inputs before having to pay for them. A lag occurs when the firm does not receive progress payments from government immediately upon incurring a cost. Both floats and lags clearly do occur in reality. Another complication is that on contracts for multiple items, some deliveries typically occur before the end of the contract. Full payment for the delivered items is usually received by the firm upon delivery. Finally, milestone payments are made on some contracts. These are interim payments over and above regular progress payments which are made contingent upon the firm's completion of some well-defined stage of a project.

Obviously, all of these complications affect the calculation of financing cost and should therefore be included in the calculation of profit if

possible. Furthermore, a relatively costless method of doing so exists and is described below.

On contracts greater than \$1 million, firms currently submit projections of expected cost broken down by month, as well as data on floats, lags, delivery times, and milestone payments.³ All these data are fed into a program called the Cash IV program to calculate a progress payment rate for the contract that will result in the firm bearing 20 percent of the total financing costs when the effects of all these complications are taken into account.⁴

The current DoD practice regarding the Cash IV program shows great evidence of the left hand not knowing what the right hand is doing. Large amounts of information are gathered and processed in a sophisticated cash flow model to calculate a progress payment rate. The resulting financing cost borne by the contractor is implicitly determined as part of this calculation. However, all of this is totally ignored in the calculation of profit. Instead, a very rough and probably incorrect approximation of financing cost is used based on almost no information.

Profit policy regulations should obviously be modified to take advantage of the Cash IV program. The Cash IV program should be modified to print out a value for the firm's financing cost. The regulations should state that when the Cash IV program is used to determine a progress payment rate, it must also be used to determine financing cost.

Three remarks should be noted about this. First, on the basis of discussions with industry participants, it seems that the Cash IV program typically produces a progress payment rate of 85 percent to 90 percent. There are two possible explanations for this. It may be that defense firms always have larger lags than floats. The second and more likely explanation is that the program is not correct and is somehow biased toward calculating overly high progress payment rates. For example, it may be that the military services are employing a biased Cash IV program as a way to give contractors higher progress payments than Congress would otherwise allow. Therefore, the program would need to be fully analyzed and determined to be correct before being employed for profit policy calculations. If the

³See 48 CFR 232.502-1 for a more complete description of which contracts are eligible for application of the Cash IV program.

⁴If the Cash IV program produces a rate less than 80 percent, 80 percent is used. However, this is never a problem in practice, as apparently the Cash IV program always produces rates larger than 80 percent.

program was biased and the services were unwilling to change it, a separate program that independently calculated financing cost using the same data input as the Cash IV program could obviously be created and used with very little difficulty.

The second remark is that current profit policy regulations contain an even more glaring inconsistency with the Cash IV methodology than simply not taking advantage of its calculations. The current regulations specify that profit for working capital is to be calculated using a progress payment rate of 80 percent even when the Cash IV rate actually being paid is higher. This generates a financial windfall for the affected firms and should obviously be corrected as part of the revision that makes profit policy calculations consistent with Cash IV.

Third, under current practice the flexible progress payment rate may not be calculated until after the award of the contract. Under the proposed revision, which would demand consistency in financing cost calculations and Cash IV calculations, the firm would be required to submit all data necessary for operation of the Cash IV program along with its proposal. Then, one calculation would produce consistent values for the firm's progress payment rate and financing cost. The calculations would be consistent in two senses. First, they would employ the same assumptions about the time pattern of cost incurrence, interest rates, etc. Second, the progress payment rate the firm actually receives would be the rate used to calculate its share of the financing cost.

F. THE PROGRESS PAYMENT RATE AS A POLICY TOOL TO INFLUENCE ECONOMIC PROFIT LEVELS

1. Introduction

A deeply entrenched mentality within the entire procurement community is that the major policy effect of changing the level of the customary progress payment rate is to change the amount of economic profit earned in the defense industry. Increases in the progress payment rate serve to increase the economic profit of defense contractors and decreases in the progress payment rate decrease economic profit. Thus, if the defense contractor community perceives that the economic profit level is too low (negative, for example), they will argue that the correct solution is to raise the progress payment rate.⁵ Similarly, if a government body perceives that the economic profit

⁵See, for example, the industry-sponsored study by the MAC Group (1988).

level is too high, it will typically argue that a solution would be to lower the progress payment rate.⁶

Changes in the progress payment rate change the level of economic profit earned on contracts because the current rules and their historical predecessors do not calculate profit for working capital correctly. Under the proposed revision, which correctly calculates the cost of working capital, this will no longer be the case. Changes in the progress payment rate will automatically generate compensating changes in profit paid for working capital costs which (at least in theory) leave firms exactly as well off.

Therefore, the proposed revision of profit would obliterate what most people currently view as the major policy debate concerning the progress payment rate level. The major point of this section is simply to argue that this is unambiguously an improvement. The overall profit level can (and should) be controlled by simply awarding higher or lower levels of profit. The level of progress payments has a number of important economic effects independent of the overall profit level and should be set at a level that strikes an optimal balance among these other concerns. To put this another way, the DoD loses a degree of policy freedom by using the progress payment rate to adjust the overall profit level. Furthermore, because all of the debate focuses on this profit-level concern, the fact that the level of progress payments has other important economic effects is lost sight of.

The next two subsections will elaborate on this argument. Subsection 2 explains in more detail why the current rule and its historical predecessors exhibit the property that changes in the progress payment rate affect economic profit. Then Subsection 3 briefly describes some other important economic effects of varying the progress payment rate (which should be considered when choosing an optimal rate).

2. The Current and Historical Policies

Before the 1987 revision of profit policy, profit for working capital was calculated as 2 percent of expected costs regardless of the level of progress payments. Thus, increases in the progress payment rate would decrease firms' financing costs without any corresponding decrease in their profit. This meant that increases in the progress payment rate would increase the economic profit of defense firms.

⁶See, for example, the Grace Commission (President's Private Sector Survey on Cost Control, 1984).

Similarly, decreases in the progress payment rate would decrease economic profit.

Since the 1987 revision, the situation is not quite as extreme. Now the progress payment rate is used to calculate a profit for working capital using the treasury rate, as discussed above. However, in Sec. 7 it was suggested that the treasury rate probably averages approximately 1-1/2 percentage points below the true cost of working capital. Thus, the pre-1987 situation still exists to a lesser extent. Because the cost of working capital is calculated using an artificially low rate, firms will benefit when government raises the progress payment rate. (The resulting reduction in firms' financing cost will be greater than the reduction in profit for working capital.) In particular, the progress payment rate is still a policy instrument that affects the economic profitability of defense contractors.

When the costs of working capital are calculated correctly, firms should be relatively indifferent to the level of progress payments they receive, because they are being fairly compensated for the financing burden they are assuming themselves. Thus, for example, if progress payments rose from 80 percent to 90 percent, the correct rule would lower profit sufficiently so that firms would be no better off. In particular, therefore, when profit on working capital is correctly calculated, the level of progress payments cannot be used as a tool to affect the overall profitability of the defense industry.

3. The Optimal Progress Payment Rate

In Subsection 2 it was argued that if the regulations correctly calculated financing cost, then the DoD could independently set the progress payment rate equal to any level it chose without worrying about the effects on economic profit levels. If the level of progress payment rate had no other economic effects, there would be no advantage to this. However this is not the case. Raising the progress payment rate results in a number of different real economic effects, some negative and some positive. The optimal level of progress payments is the level at which the marginal benefits from raising the rate any further would be outweighed by the marginal costs. The DoD should attempt to set the progress payment rate equal to this optimal level. Of course, in reality it is probably impossible to precisely calculate the optimal level. Nonetheless, the correct policy would still be to attempt to roughly assess the costs and benefits as well as possible and choose the progress payment rate accordingly. The DoD loses the freedom to do this when it instead chooses to use the progress payment rate to control the level of economic profit.

It is beyond the scope of this report to present a complete theory of progress payments. Nonetheless, some of the major real economic effects of the progress payment rate will be described to show that the choice of the level of this rate does have important effects. The major benefit to raising the progress payment rate is that it reduces the government's real cost of purchasing the item contracted for to the extent that the federal government's borrowing cost is less than the firms'. There are two major costs to raising the rate. First, when a firm is financing 100 percent of its inventories it will take great care not to order raw materials before they are necessary and to manage inventories as efficiently as possible in other ways. As the firm bears a lower percentage of financing costs, it will become less concerned about this. Thus, the possibility that firms will maintain inefficiently large inventories of raw materials and parts grows larger as the progress payment rate rises. Second, to the extent that the firm receives progress payments of less than 100 percent, the government is withholding part of the payment until delivery. This means that the firm will have a greater incentive to finish on time or early. Furthermore, if costs rise unexpectedly, the firm's investment in working capital essentially acts as a performance bond. That is, the firm will not receive reimbursement for its working capital investment unless it finishes. Thus, lower levels of progress payments provide the government with more assurance that the firm will agree to complete the contract even if costs rise unexpectedly.

The task facing DoD policymakers is to assess the relative magnitude of these costs and benefits and to somehow choose a rate that attempts to strike a balance between the various factors. Incidentally, there is no reason to believe that the optimal progress payment rate policy would be to set a single rate. One might imagine that different rates could be established to apply to different circumstances. For example, large firms with many defense contracts are less likely to renege on any given contract than are small firms with only one or two defense contracts. Therefore, the need to set the progress payment rate low to create a performance bond may be less important for large defense contractors. If this is true, the optimal progress payment rate policy might establish a higher rate for major defense contractors than for other firms.

9. A WORKING CAPITAL ADJUSTMENT FOR COST-TYPE CONTRACTS

A. INTRODUCTION

Fixed-price-type contracts receive progress payments only on cost. This was the situation modeled in Sec. 4. However, cost-type contracts also receive progress payments on profit. The purpose of this section is to show how the profit calculations for cost-type contracts should be adjusted to reflect this fact.

B. THE THEORETICAL MODEL

On cost-type contracts, progress payments are paid on a fraction of profit equal to the fraction of costs incurred. That is, if a firm incurs costs equal to the fraction f of total expected costs in some period, the government pays progress payments on $f\pi$ in that period. Therefore, the model of Sec. 4 must now be changed so that at time t the firm receives an additional amount equal to

$$\frac{C_t}{E(\tilde{C})} \alpha \pi, \quad (9.1)$$

where π is the profit. The sum of these n payments is then subtracted from the final payment to the firm.

Two more pieces of notation will be useful to present the result. First, let π^* denote the value of profit calculated under the old rule of Eq. (4.14), i.e., π^* is the value of profit calculated under the assumption that progress payments are not made on profit. Let D be defined by

$$D = \frac{E(\tilde{C})}{E(\tilde{C}) + \alpha F(1 - \psi)}. \quad (9.2)$$

Recall that F is the total risk-neutral financing cost defined by Eq. (4.11) and ψ is the risk parameter defined by Eq. (4.16). Notice that D is between 0 and 1.

Proposition 5 now presents the new minimum profit rule.

Proposition 5:

Suppose that progress payments are paid on profit as described above. Then the correct minimum profit rule is given by

$$\pi = D\pi^* . \quad (9.3)$$

Proof:

See App. E. Q.E.D.

Thus, according to Proposition 5 the correct value of profit when progress payments are paid on profit is calculated in two steps.

Step 1: Calculate profit as though progress payments were not paid on profit.

Step 2: Multiply the result by the deflation factor D.

Recall that the procedure suggested for practically implementing the pricing formula was to assume that ϕ and ψ were equal and denoted by ω . When this is done, D would be estimated by replacing ψ by ω in Eq. (9.2).

Proposition 5 will continue to apply to generalized models considered in later sections when profit is calculated for reimbursement for other unrecognized costs, for facilities' capital, or as pure economic profit. To correct for the fact that progress payments are made on profit, one should first calculate profit assuming that no progress payments on profit are made and then apply the deflation factor D as calculated in this section. Therefore, in subsequent sections only the rule for calculating profit under fixed-price-type contracts (i.e., when there are no progress payments on profit) will be explicitly considered. It will always be the case that the appropriate profit level for a cost-type contract is calculated by multiplying by D.

C. THE UNIFORM CASE

This subsection calculates the deflation factor for the case where costs are incurred at a uniform rate. It will be seen that the size of the correction is significant enough that it should probably not be ignored.

The approximation derived in App. D will be used. Thus, F is given by

$$F = R_F \frac{\ell}{2} E(\tilde{C}) . \quad (9.4)$$

It will be assumed that α equals 1 (since cost-type contracts receive 100 percent progress payments) and that ψ has the normal value of 0.037. Substitution of these values into Eq. (9.2) yields

$$D = \frac{2}{2 + 0.963 R_F \ell} . \quad (9.5)$$

Table 9.1 presents the value of D for various values of ℓ and R_F . The deflation is more significant (i.e., D grows smaller) for longer contracts and higher interest rates because the significance of progress payments is greater. Note that even for a two-year contract with an 8 percent interest rate, profits should be decreased by 7 percent. For a three-year contract with a 12 percent interest rate, the deflation should be 15 percent. Thus, very plausible contract lengths and interest rates generate sizable corrections.

D. POLICY IMPLICATIONS

The size of this correction is probably significant enough to warrant its inclusion as a separate component to profit policy. Thus, profits for fixed-price-type and cost-type contracts would be calculated in a similar fashion using the assumption that progress payments are not paid on profit. Then, for cost-type contracts the resulting profit would be multiplied by a deflation factor to correct for the fact that progress payments are paid on profit.

Formula (9.2) provides an extremely convenient method for calculating this deflation factor. The negotiator obviously knows $(1 - \alpha)$ and $E(\tilde{C})$. Furthermore, he has already determined ω and F to calculate previous components of profit. Thus, the negotiator simply needs to plug in the predetermined values to calculate D .

Table 9.1
Values of D

R_F	ℓ					
	0.5	1	2	3	4	5
0.04	0.991	0.981	0.963	0.945	0.929	0.912
0.08	0.981	0.963	0.929	0.896	0.867	0.839
0.12	0.972	0.945	0.896	0.852	0.812	0.776
0.16	0.963	0.929	0.867	0.812	0.764	0.722

Note that the formula in Eq. (9.2) has the property that it automatically employs the same assumptions about cost incurrence as were used in the calculation of working capital. Thus, the two calculations are perfectly consistent.

10. PROFIT FOR OTHER UNRECOGNIZED COSTS

A. INTRODUCTION

Section 9 completed the analysis of the simplified case where the only unrecognized costs were risk-bearing and working capital. This section maintains the assumption that there is no facilities capital but considers the existence of other unrecognized costs besides risk-bearing and working capital. Section 11 then goes on to consider the costs of facilities capital.

At least three significant classes of economic costs, which are not related to capital or risk-bearing and which are not recognized by the government accounting system as costs, are shown to exist for defense contractors. Furthermore, references in the current regulations can be found that arguably can be interpreted as identifying two classes of these unrecognized costs and specifying that profit should be paid to reimburse them.

B. REALLOCATION OF THE OVERHEAD COST OF MANAGEMENT

Although this report's general approach has been to ignore issues related to cost allocation, it will be briefly considered here because the language of the regulations so clearly suggests that it plays a role in determining one element of profit. To ignore cost allocation issues, two conditions are necessary.

- (i) Every expense of the firm is unambiguously identifiable with one and only one contract.
- (ii) The government and the firm are able to agree on an objectively verifiable cost-accounting system that correctly allocates each expense.

In this subsection, assumption (ii) will be relaxed. In particular, it will still be assumed that every expense can be unambiguously identified with a single contract. Furthermore, the firm will be assumed to know the correct allocation for each expense. However, it will be assumed that not all expenses are easily identified with their particular contract by some objectively verifiable rule. Thus, allocation methods for the purposes of calculating the cost figures used by government will not necessarily be accurate.

An example may make this more clear. This is, in fact, the example the regulations consider. Management effort and time is devoted to all of the firm's contracts. In principle, a firm could perhaps estimate the fraction of management effort required for different contracts. Thus, in principle, the firm could allocate the cost of management correctly across its contracts. However, there is clearly no objectively verifiable method to do this. Thus, to calculate the cost of management for each contract, total management cost is simply allocated across all contracts using a base of direct costs. However, this may result in large inaccuracies in some cases. For example, a contract with large direct costs may be very standard and require little management effort whereas a smaller contract involving state-of-the-art technology, tight deadlines, and the integration of many subcontractors' products may involve very large amounts of management effort. Thus, the cost of management effort is overstated in the first case and understated in the second case relative to the true costs.

It appears that current regulations attempt to correct for this possible misallocation to some extent by allowing negotiators to raise the performance profit component of profit when management effort is unusually high and to lower it when management effort is unusually low. Specifically, in the section of performance profit labeled as management, the regulations state the following:

The contracting officer may assign a higher than normal value in those cases when the management effort is intense. The following are indicators that such conditions may exist: The value-added by the contractor is both considerable and reasonably difficult; the effort involves a high degree of integration or coordination. . . . A maximum value for management may be justified under conditions such as the following: efforts requiring large scale integration of the most complex nature; major international activities requiring significant management coordination; or efforts with management milestones of critical importance. . . . The contracting officer may assign a lower than normal value in those cases where the management effort is minimal. The following are indicators that such a condition may exist: a mature program where many end item deliveries have been made; the contractor adds minimum value to the item; routine efforts which require minimal proposals.¹

C. CORRECTING FOR DISCREPANCIES BETWEEN MONETARY AND OPPORTUNITY COSTS OF TALENTED EMPLOYEES

The key fact underlying this idea is that the firm has a scarce number of truly talented engineers and their salary differentials will gener-

¹48 CFR 215.9-1,a,ii.

ally not fully reflect their ability differences. Peck and Scherer (1962) stress this point:

The highly talented technical and managerial personnel in a weapons firm affect the success or failure of programs to a degree rarely reflected in salary differentials. Since few if any companies are so well staffed that they can assign first-rate scientists, managers, and engineers to every project they undertake, important qualitative resource allocation decisions must be made.²

This creates the following problem. Suppose a firm has two engineers, each earning the same salary of x . However, one engineer is much more talented. On the firm's commercial business the talented engineer would generate profits much greater than would the less-talented engineer. However, it may be that the DoD program manager for a particular project believes that he also requires the talented engineer. The cost to the firm of this engineer is not simply the wage cost x . It is also the profits that would be forgone by switching the engineer from commercial business to government business. That is, the firm would be unwilling to accept a contract that specified that its talented engineer would be used unless the price included the opportunity cost of forgone profits.

The current regulations seem to indicate that profit can be increased to compensate for this opportunity cost. In particular, in the section describing technical risk the following statement is made:

Extremely complex, vital efforts to overcome difficult technical obstacles which require personnel with exceptional abilities, experience, and professional credentials may also justify a value significantly higher than normal.³

Even though it is included in the section describing technical risk, it clearly seems to be alluding to the problem of unrecognized costs.

D. UNALLOWABLE OPERATING EXPENSE

DoD regulations specify that some expenses that firms incur as part of their operating cost of performing defense contracts not be recognized for the purposes of calculating the cost of a contract. These expenses are called unallowable costs.⁴ An important example concerns

²Peck and Scherer (1962), p. 501.

³48 CFR 215.9-1,a,3,i,A.

⁴DoD regulations also specify that a wider variety of other expenses that are not operating costs on defense contracts cannot be charged as a cost on defense contracts.

various elements of nonwage employee compensation. For example, alcohol expenses at firm-sponsored parties for employees are unallowable. In fact, most firm-sponsored parties are unallowable. Subsidizing employee meal expenses is also unallowable and many other sorts of benefits such as company cars are unallowable. Another large class of examples concerns operating expenses that might be classified as "extravagant" in some sense. Thus, first-class airfare is unallowable. In general, defense contractors can charge only per-diem rates for travel consistent with those the federal government allows for its own employees. Part 31 of the *FAR* contains a complete listing of unallowable cost items.⁵

Regardless of allowability, contractors do incur unallowable operating costs as part of their defense work. Thus, contractors seem to feel that certain elements of these expenses are necessary even if they cannot be included as a cost for the purposes of negotiating a price (or for being reimbursed on cost-reimbursement contracts). This creates the following problem. Suppose that government correctly calculates a price for a contract, including a return to risk bearing and capital usage, but ignores x dollars of unallowable expenses. From the firm's standpoint the contract price is x dollars too low. Thus, it will refuse to accept the contract. That is, to calculate the minimum price that the contractor will accept, the government must include an allowance for unallowable costs that will be incurred as part of the contract. This, by definition, must be called a profit, since it is not a payment for an allowable cost.

The interesting question this raises is why the regulations make certain types of operating costs for defense work unallowable. One theory is that Congress has simply disallowed certain expenses that it did not like, and no good economic justification exists. However, an economic rationale for this policy may exist. It may be that certain types of expenses provide large private personal benefits as well as productive benefits. Thus, there is a danger that firms might overuse these inputs if they were allowed as a cost. The optimal scheme may be to disallow these expenses but then provide a "profit" to compensate firms for them. That is, when firms are likely to overuse some input for their private gain, it may be better to reward them a fixed

These are also called unallowable costs. For example, interest expense is an unallowable cost. So is advertising of the firm's commercial products. The discussion in this subsection focuses on expenses that are clearly operating costs of performing a defense contract but are nonetheless unallowable.

⁵48 CFR 131.

sum as profit and let them bear the full marginal cost of their expenses.

This report's purpose is not to explore incentives for cost-minimizing behavior and this subject will not be pursued further here. The report's important idea is that unallowable operating costs of defense production must be reimbursed as part of a correct pricing rule. By definition, these are an element of profit.

It is important to stress that this argument is referring only to operating costs on defense contracts. That is, there is a wide range of unallowable costs, such as interest expense, IR&D and B&P expense, and advertising expenses for commercial products, which are not operating costs of defense contracts; i.e., they are not costs that must be incurred after the date of signing the contract to complete the contract. It is not clear whether unallowable operating costs are significant or not. Although "unallowable costs excluding IR&D, B&P, and interest expense" average 1.09 percent of allowable costs,⁶ it seems likely that a very large part of this 1.09 percent is not operating costs on defense contracts. Rather, it is items such as advertising. Thus, this may not be a significant enough item to worry about. Unfortunately, no data on the size of unallowable operating costs on defense contracts are available, to the best of my knowledge. More data need to be gathered on this point.

Current regulations do not explicitly consider this issue. Perhaps even if it was determined to be a significant enough item to consider, it might be better to disguise the payment. Congress is not likely to respond favorably to a regulation explicitly reimbursing firms for unallowable costs, regardless of the economic validity of the regulation.

E. INCORPORATION OF OTHER UNRECOGNIZED COSTS INTO THE PRICING RULE

The model considered in Sec. 4 will now be changed in one respect. It will be assumed that the firm will spend U_t dollars on other unrecognized costs in period t , where U_t is given by

$$U_t = \delta E(\tilde{C}_t) . \quad (10.1)$$

⁶DoD (1985a), Appendix I, Volume II.

In the above equation it is assumed that unrecognized costs are incurred in some constant proportion to recognized costs. In particular, for purposes of contract estimation, the contracting officer must estimate the percentage of expected costs that unrecognized costs are equal to. Also, for notational simplicity it is assumed that the values of U_t are known with certainty at the time of contracting. It is absolutely straightforward to consider the alternative assumption of

$$U_t = \delta C_t , \quad (10.2)$$

where other unrecognized costs are uncertain. However, this makes no difference to the qualitative conclusions and the notation is somewhat more cumbersome.

The extra profit that is required because of the unrecognized costs will now be calculated. First, consider the PPC. On the day of delivery the firm will now spend an extra $\delta E(\tilde{C})$. Therefore, its profit must be increased by this amount. Profit on the PPC is now given by

$$\pi_{PPC} = \gamma \phi E(\tilde{C}) + \delta E(\tilde{C}) . \quad (10.3)$$

Now consider the PFC. The firm will now loan the government an extra $\delta E(C_t)$ in period t . Note that no progress payments are made on these costs because the accounting system does not recognize them. Therefore, $\delta E(C_t)$ is not multiplied by $(1 - \alpha)$. The profit of the firm must therefore be increased by

$$\delta \sum_{t=1}^n E(\tilde{C}_t) \left[(1 + r_F)^{n+1-t} - 1 \right] , \quad (10.4)$$

which can be rewritten as

$$\delta F . \quad (10.5)$$

Therefore, the profit on the PFC is given by

$$\pi_{PFC} = (1 + \psi)(1 - \alpha)F + \delta F . \quad (10.6)$$

The correct minimum profit rule is given by the sum of Eqs. (10.3) and (10.6). This can be written as

$$\pi = \phi \gamma E(\tilde{C}) + (1 + \psi)(1 - \alpha)F + \delta(E(\tilde{C}) + F) . \quad (10.7)$$

In particular, the extra term

$$\delta(E(\tilde{C}) + F) \quad (10.8)$$

is added to compensate for the existence of these unrecognized costs. Note that the extra profit does not simply equal $\delta E(\tilde{C})$. The amount δF must also be included to reflect the fact that the firm finances these expenses over the lifetime of the contract. Furthermore, the financing cost is relatively more significant than for recognized costs because the firm finances 100 percent of them instead of merely 20 percent.

F. POLICY IMPLICATIONS

The above analysis has shown that there are valid economic reasons to expect various categories of unrecognized costs to exist other than the costs of risk bearing and capital. Furthermore, passages in the regulations can be interpreted as describing some of these costs. The major problem with the current regulations is that the concept that other unrecognized costs may exist and that reimbursement for them needs to be calculated as part of profit is completely obfuscated by the current format. Vague references to various possible categories of unrecognized costs are scattered throughout the "performance profit" section. However, references to risk are intermixed in a totally unorganized fashion. Furthermore, as will be shown in Sec. 12, the performance profit section also describes reasons to actually give economic profit to contracts. All of these discussions are intertwined in a seemingly random fashion and no effort is made to provide any understandable conceptual structure. Thus, the goal of providing a clear conceptual structure for understanding the nature of profit and how to calculate it is totally unsatisfied by the regulations. In particular, the current regulations do nothing to structure policymakers' thinking about profit, nor do they give contracting officers clear useful guidance to help them understand the nature of and correctly calculate profit.

The solution is to create a separate section of the profit policy regulations entitled "other unrecognized costs." This section would specify a normal value for δ and an allowable range. The job of the contracting officer would be to select a value of δ from the allowable range. The

section would clearly state that its purpose was to identify the magnitude of other unrecognized costs. It would then describe categories of these costs such as misallocation of management effort, opportunity costs of talented employees, and any other categories that policymakers thought were significant. The contracting officer would be instructed to choose a value of δ larger (smaller) than average if these costs seemed larger than average for the contract in question.

Five remarks should be noted about this. First, it is unlikely that the contracting officer can form sufficiently precise estimates for there to be any value in estimating separate values of δ for each subcategory of unrecognized costs. Thus, only a single value of δ would be chosen.

Second, as discussed above, it might be wise to not explicitly list unallowable operating expenses as a category of unrecognized cost. There would be little loss from this omission because it is unlikely to vary significantly from firm to firm in any event. Thus, there would be no need for the contracting officer to explicitly be aware of this factor to adjust δ .⁷

Third, the normal value of δ should be determined. It will first be estimated for each of the three categories of unrecognized costs described above. Then, the normal value of δ equals the sum of these three values.

Consider the costs of misallocation of effort and opportunity costs of talented employees. Note that any given contract should be just as likely to require *below*-average management effort or talent as *above*-average management effort or talent. By definition, not all contracts can require above-average values. This means that any given contract should be just as likely to exhibit a negative value of δ as a positive value with respect to these two categories of costs. Thus, the normal values of δ with respect to these two categories should be zero and the allowable range should include negative as well as positive values.

Now consider the third class of unrecognized costs—unallowable operating costs. As discussed in Subsection C, no good data are available on the size of this cost. The available figure of 1.09 percent of allowable cost includes both operating costs on defense contracts and

⁷There is also a more subtle point in incentive theory involved here. Suppose that the purpose of unallowable costs is to have the firm bear 100 percent of these costs on the margin as described in Subsection C. Then, the contracting officer should not adjust δ up or down in response to a particular firm's level of unallowable costs. Rather, all firms should receive the same payment for their unallowable costs regardless of their individual levels of these costs.

a wide range of other unallowable expenses that are related to the firms' commercial business. In the absence of better information, the estimate of approximately half this value, or 0.55 percent of allowable cost, will be assumed to be reimbursement for unallowable operating expenses for the purpose of this analysis.

Since the normal values of the first two categories of unrecognized costs should be zero, the normal value for the entire section should simply be the normal value for the third category. Thus, a normal value for δ of 0.55 percent (i.e., $\delta = 0.0055$) is indicated by the above analysis. Further empirical work regarding the value of unallowable operating expenses might modify this value. Policymakers could well identify other categories of unrecognized costs, which could also be included in the description of factors and which should cause the contracting officers to choose a higher or lower value of δ . Some of these other categories might well have positive normal values, in which case the normal value of δ would be raised to reflect this.

Fourth, the allowable range for δ could conceivably be quite large. One could imagine significant variations in the required level of management effort and talent of employees. The range should almost certainly include negative values as well. A concept not explicitly recognized in the current regulations is that by definition there must be contracts with below-average requirements for management effort and employee talent. Not all contracts can have above-average requirements.

Fifth, the major objectively verifiable indicator of high levels of opportunity cost or underallocated managerial effort is probably technical complexity and uncertainties and tightness of delivery schedule. Thus, the description of qualitative factors influencing the level of ω in the contract risk section will be somewhat similar to the description in this section. The major difference in the determination of δ is the importance of *relative* levels of technical complexity among the firms' contracts. Even if all of them are technically complex they cannot all be above-average for the firm.

This might perhaps raise the issue in the reader's mind of whether the "technical risk" section of performance profit might be interpreted as the DoD's attempt to compensate firms for other unrecognized costs. It has the features that high levels of technical complexity cause higher profit and that the value of γ (the cost-sharing coefficient) does not affect the profit, which are consistent with this theory. Recall that in Sec. 6 the alternative interpretation was advanced that it was meant as a return to risk and that policymakers "forgot" to multiply the profit by γ . This interpretation was strongly supported

by the historical levels of the risk parameter. However, it is conceivable that policymakers explicitly and consciously did not multiply by γ because they had other unrecognized costs in mind. Given the fuzzy language and loose use of words such as "risk," there is really no way to know from simply reading the regulations. A redrafted regulation that was conceptually explicit about the nature of profit would not have this problem.

11. THE RETURN TO FACILITIES CAPITAL

A. INTRODUCTION

The standard rule of the current policy for reimbursing facilities capital usage has four rather striking features.

1. The return to facilities capital is generally much higher than the return to working capital.
2. The return to facilities capital is calculated independently of the risk of the particular contract it is being used on. Thus, a very risky fixed-price contract and a cost plus fixed fee contract using the same amount of capital would receive the same profit for capital use.
3. Different types of facilities capital receive different returns.
4. The time value of money is ignored. That is, a contract that lasts twice as long receives only twice the profit for facilities capital.

This section has two major points. First, the first three features described above are perfectly consistent with an economic analysis of these issues. The key economic idea in this section underlying this conclusion is that the risk one considers when calculating all aspects of profit that have been discussed up until now is totally different from the risk that one considers when calculating a return to facilities capital investment. The former is termed *intracontract* risk and the latter is termed *intercontract* risk.

The second major point concerns the fourth feature. The current rule is obviously incorrect in ignoring the time value of money. This report shows that the correct rule should calculate this time value by using the risk-free rate. Although capital may receive a very large risk premium, the delay of payments until the end of the contract does not affect risk. Thus, delay should be accounted for at the risk-free rate. This has two implications. First, because the correct rule is to compound at the relatively low risk-free rate, the error from ignoring the time value of money is less than might be expected. Thus, although the rule should be corrected, it is not a source of extremely large error in the current regulations. Second, a rule that calculated the time value of money by using an interest rate considerably higher than the risk-free rate would generate at least as great an error as the existing rule.

B. THE MODEL

The critical difference between facilities capital investment and working capital investment is that facilities capital investment outlasts a single contract. Thus, a totally different type of risk needs to be considered. Up until now, the only risk considered has been *intra*-contract risk. This is the risk that a firm accepts when it signs a particular contract. The correct valuation of the cost of facilities capital involves considering *inter*contract risk. This is the risk that a firm accepts when it invests in a long-lived piece of facilities capital without specific contractual guarantees regarding the return that this investment will earn over its lifetime.

Two different factors can create intercontract risk. First, the firm may not know whether it will receive contracts over the entire lifetime of the capital. For example, Congress may choose not to fund a particular program. Second, the firm may not be able to predict exactly the return it will receive even if it does succeed in winning contracts in the future. For example, Congress or the DoD may simply choose to change the formal rules for calculating profit. Even if the formal rules are not changed, DoD may simply choose to adopt more or less harsh negotiating positions.

A key condition affecting both of the above factors is the overall level of procurement activity. As the overall level of procurement rises, a firm's chances of winning a contract will rise. However, it is probably also the case that overall high levels of capacity use in the industry will result in the firm having a stronger negotiating position and thus being able to negotiate higher returns.

The key fact to note is that these factors concern the terms (and possibly existence) of contracts that are not yet signed when the facilities capital investment is made. Thus, the element of risk concerns the question of future contract terms. All other elements of profit considered up until now could be wholly calculated and analyzed within the context of a single contract. In particular, the only risk was the risk of cost uncertainty in performing the specific signed contract.

This idea will now be illustrated in a simple model where the nature of intercontract risk is that the firm may not always receive a contract.¹ Consider the simple contract analyzed in Sec. 4. It will be convenient to assume one-year periods in order to deal with

¹It is straightforward to develop exactly the same points in a model where the terms of future contracts as well as whether a contract is received are random. The above model is used for expositional simplicity.

annualized rates in the formulas. Suppose that the contract lasts for ℓ years and let R_F denote the annualized risk-free rate (which will be assumed to be constant over time for simplicity). Assume that the firm must invest in capital with a cost of K dollars to perform the contract. For simplicity, assume that the capital lasts forever. Thus, the issue of depreciation can be ignored. Furthermore, assume that the capital has no alternative use and no resale value.² Assume also that a new competition to assign a contract is held every ℓ years, beginning at time 0. Finally, the firm invests K dollars at time 0. Thus, the sequence of events is as follows.³

Period 0: The firm invests K dollars.

The firm attempts to win a contract.

Period ℓ : The firm delivers the product if it received a contract in period 0.

The firm attempts to win the next contract.

Period 2ℓ : The firm delivers the product if it received a contract in period ℓ .

The firm attempts to win the next contract.

And so on.

When a firm wins a contract, the profit rule of Sec. 4 is used to calculate a profit for all items except facilities capital so that the net present value of a contract to the firm is zero ignoring facilities capital.⁴ In addition, a return of d dollars is given to the firm for its facilities capital if it wins a contract. If the firm wins no contract, it receives no payment from the government for the next ℓ periods.

Intracontract risk already exists in this model because the costs of performance are random if the firm receives a contract. The profit rule of Sec. 4 that is used when the firm wins a contract takes this

²The significance of these assumptions will be discussed below.

³It would be more realistic to alter this sequence of events in two ways. First, it could be assumed that the firm does not have to invest in K until it wins its first contract. Second, it could be assumed that a firm that did not win a contract could immediately try to win a contract in the next period as opposed to waiting ℓ years. I have solved this model and exactly the same qualitative conclusions are derived but with much more complex algebra. Therefore, the simpler assumptions are made here for expositional clarity.

⁴Assume for expositional simplicity that no economic profit is given. The same points carry through, however, even when economic profit is given.

into account. Now intercontract risk will be introduced as follows. Assume that the overall level of capacity use of the industry varies randomly from period to period. Let $\bar{\theta}_t$ denote this rate. It will be called the utilization rate. If the firm is attempting to receive a contract in period t , assume that whether it receives one is determined as follows. First, θ_t (the realization of $\bar{\theta}_t$) is drawn. Then, the firm is given a contract with probability θ_t . (Imagine that a large number of balls are put into an urn with the fraction θ_t of them white and $(1 - \theta_t)$ black. Then a ball is drawn and the firm receives a contract only if the ball is white.)

It will be assumed that $\bar{\theta}_t$ covaries nonnegatively with \bar{R}_M^t in order that the firm be (weakly) averse to this risk. For simplicity, it will be assumed that $\bar{\theta}_t$ is independent of market returns from other periods and that the $\bar{\theta}_t$ are i.i.d. In particular, the values of $\text{cov}(\bar{\theta}_t, \bar{R}_M^t)$ and $E(\bar{\theta}_t)$ do not depend on t . Denote their common values as follows.

$$\sigma = \text{cov}(\bar{\theta}_t, \bar{R}_M^t) \quad (11.1)$$

and

$$E = E(\bar{\theta}_t) . \quad (11.2)$$

Assume that σ is nonnegative and less than E/λ , where λ is the market risk coefficient in the CAPM formula as described in Sec. 3.

$$0 \leq \sigma \leq E/\lambda . \quad (11.3)$$

This guarantees that in the CAPM formulas the risk of the program is negatively valued but the risk is not so great that the firm would never purchase capital. Thus, Eq. (11.3) is simply a technical assumption that guarantees that the problem is well-behaved.

Let v denote the following.

$$v = E - \lambda \sigma . \quad (11.4)$$

Since $E \leq 1$, assumption (11.3) implies that v is between 0 and 1. It can be thought of as the risk-adjusted expectation of θ . When the risk associated with θ is larger (i.e., σ is larger), the expected value is adjusted further downward. If the firm will receive the project with probability 1 every time, then v equals 1. However, any decrease in

the expected value of θ or increase in the risk associated with θ causes v to decrease below 1.

It will turn out that a particular monotone transformation of v will play a role in the pricing formula. Therefore, this transformation will be defined.

Definition:

The facilities capital risk premium (FCRP), denoted by A , is defined as follows.

$$A = R_F \frac{1-v}{v} . \quad (11.5)$$

The FCRP = 0 when $v = 1$, increases as v decreases, and converges to ∞ as v converges to 0. Therefore, the FCRP = 0 when the firm will always receive a contract with certainty. As the expected usage level, E , falls or the risk of the usage level, σ , increases, the value of the FCRP increases.

Following the same procedure as in Sec. 4, the value of the program to the firm calculated at period 0 will be calculated as a function of d . Then, the smallest value of d such that the value is nonnegative will be calculated. This is the minimum profit that the government must promise the firm to induce it to invest in capital. This will be called the minimum profit rule for facilities capital and will be denoted by π_K . Proposition 6 presents the value of π_K .

Proposition 6:

The minimum profit rule for facilities capital is given by

$$\pi_K = \sum_{t=1}^{\ell} (R_F + A) K (1 + R_F)^{\ell-t} . \quad (11.6)$$

Proof:

See App. F. Q.E.D.

Proposition 6 has a straightforward interpretation. Suppose that whenever the government awarded an ℓ year contract to the firm it promised to pay the firm

$$(R_F + A)K \quad (11.7)$$

dollars for facilities capital use at the end of every year. Consider the period t payment. This occurs $(\ell - t)$ years before the end of the contract. Therefore, paying the firm Eq. (11.7) at the end of period t would be equivalent to paying it

$$(R_F + A)K(1 + R_F)^{\ell - t} \quad (11.8)$$

dollars at the end of the contract. Note that the compounding is done at the risk-free rate, since moving the payment $(\ell - t)$ years into the future only creates a delay, not any risk. Summation of the terms in Eq. (11.8) for $t = (1, \dots, \ell)$ yields Eq. (11.6). Therefore, the correct formula in Eq. (11.6) can be thought of as requiring an annual payment on capital at the rate of $(R_F + A)$. Since payments are delayed until the end of the contract, the formula also includes appropriate compensation for this delay.

One comment about this formula should be noted. The FCRP is not simply a "risk premium" in the sense of compensation for uncertainty. Even if the firm were risk-neutral and thus $\lambda = 0$, the formula for the FCRP would be

$$A = R_F \frac{1 - E}{E} \quad (11.9)$$

In particular, as the expected use level falls below 1, even a risk-neutral firm must receive more than the risk-free rate of return during periods when its facilities are used, to compensate it for the times when its facilities are unused and it receives no payment. For example, if $E = 1/2$ then $A = R_F$. That is, if a risk-neutral firm receives the contract only one-half the time, it must be paid double the risk-free rate when it does receive a contract.

However, in the minimum profit rule, A is the amount that the return is increased over the risk-free rate. This makes it very natural to term it a risk premium. Certainly, this would be the most natural term to use in the regulations. Therefore, in this report, A will be called a risk premium even though it is actually a premium meant to compensate for the expected value as well as the uncertainty of underuse. (In an earlier version of the report, the term "risk adjusted underutilization premium" was used. This proved to be more awkward than the present term.)

It will also be useful to rewrite the formula for π_K in a slightly different fashion. This is done in Proposition 7.

Proposition 7:

The minimum profit rule for facilities capital, Eq. (11.6), can be rewritten as

$$\pi_K = (R_F + A)K \left\{ \frac{(1 + R_F)^\ell - 1}{R_F} \right\}. \quad (11.10)$$

Proof:

This is proved as Lemma 1 in App. F. Q.E.D.

This is useful for two reasons. First, Eq. (11.10) can be used even when ℓ is not an integer number and it is somewhat simpler to calculate. Therefore, it is a better formula to use in the regulations. Second, it will facilitate a comparison of the optimal rule with the actual rule. This will be discussed next.

C. A COMPARISON OF THE CORRECT RULE AND THE CURRENT RULE

As explained in Sec. 2, the current regulation divides capital into three categories—land, buildings, and equipment. If the risk-free rate is substituted for the treasury rate, the current rule for reimbursing capital of type i is given by

$$(R_F + B_i)K_i \ell, \quad (11.11)$$

where K_i is the net book value of capital of type i , ℓ is the length of the contract, and B_i can be viewed as a risk premium chosen by the contracting officer. For each type of capital the regulations give a normal value and allowable range for B_i . These are contained in Table 2.5.

By comparing Eqs. (11.10) and (11.11), it can be seen that there is only one difference in the form of the rules. The term

$$\left\{ \frac{(1 + R_F)^\ell - 1}{R_F} \right\} \quad (11.12)$$

in Eq. (11.10) is replaced by ℓ in Eq. (11.11).

This can be interpreted as follows. The correct rule in Eq. (11.6) was interpreted as providing a payment of $(R_F + A)K$ each period and compensation for the delay of all payments until the end of the contract. Suppose that a rule ignoring the time value of delay were created. This would simply pay the firm $(R_F + A)K$ for each of the ℓ years or

$$(R_F + A)K\ell . \quad (11.13)$$

This is the form of the current rule. Thus, the current rule can be interpreted as ignoring the time value of delay.

D. THE FOUR MAJOR FEATURES OF THE CURRENT RULE

The four major features of the current rule identified by the introduction are discussed below in light of the above analysis.

Feature 1:

The return to facilities capital is generally much higher than the return to working capital.

The model of Subsection B does not necessarily predict that the required rate of return on facilities capital will be higher than that on working capital. It shows, however, that the factor that determines facilities capital profit (intercontract risk) is different and unrelated to the factor that affects working capital profit (intracontract risk). Thus, there is no economic reason to expect the required profit rate on facilities and working capital to be the same.

Feature 2:

The return to facilities capital is calculated independently of the risk of the particular contract it is being used on.

Once again, this is a straightforward implication of the fact that facilities capital profit depends on intercontract risk and not on intracontract risk.

Feature 3:

Different types of facilities capital receive different returns.

In the model of Subsection B all capital was assumed to have absolutely no resale value and absolutely no alternative commercial use. In reality, different types of capital exhibit different degrees of fungibility and resale value. It would be straightforward to adapt the

above model to show that, as capital becomes more fungible or less sunk, the required profit rate decreases, because the firm can find alternative uses for the capital if it is not required for government work.

The current rule distinguishes between three types of facilities capital—land, buildings, and equipment. It gives the lowest return to land and highest return to equipment. This distinction may broadly correspond to different degrees of fungibility and resale value. Certainly, a piece of land could be resold and an advanced machine line for constructing a particular weapon probably could not. This policy could probably benefit from some further refinement as will be discussed in Subsection E.

Feature 4:

The time value of money is ignored. That is, a contract that lasts twice as long receives twice the profit for facilities capital.

As explained in Subsection C, this is the one feature of the current rule *not* consistent with the correct rule. The current rule uses Eq. (11.13) instead of Eq. (11.10). To investigate the size of this error, let $\varepsilon(R_F, \ell)$ denote the percentage error from using Eq. (11.13) instead of Eq. (11.10) given the values of R_F and ℓ . This is defined by

$$\varepsilon(R_F, \ell) = \frac{\ell - \left\{ \frac{(1 + R_F)^\ell - 1}{R_F} \right\}}{\left\{ \frac{(1 + R_F)^\ell - 1}{R_F} \right\}} \times 100\% . \quad (11.14)$$

Values of $\varepsilon(R_F, \ell)$ for various values of R_F and ℓ are displayed in Table 11.1.

Since the current rule ignores the time value of delay, the extent of underestimation grows more severe for longer contracts and higher interest rates. Moderately large errors can result for plausible values of R_F and ℓ . For example, when $R_F = 12$ percent and $\ell = 3$, the current rule underestimates facilities capital cost by 11 percent.

The size of the error is perhaps small enough that one could justify ignoring it if the costs of correcting it were large. However, this does not appear to be the case. Equation (11.10) is not particularly more complicated than Eq. (11.13). It simply involves calculating an

Table 11.1
Values of $\varepsilon(R_F, \ell)$
(in percent)

R_F	ℓ					
	0.5	1	2	3	4	5
0.04	+1	0	-2	-4	-6	-8
0.08	+2	0	-4	-8	-11	-15
0.12	+3	0	-6	-11	-16	-21
0.16	+4	0	-7	-14	-21	-27

NOTE: $\varepsilon(R_F, \ell)$ is defined by Eq. (11.14).

exponent. The values of Eq. (11.12) could always be provided in tabular form for various values of R_F and ℓ as an alternative to asking contract officers to calculate a formula with an exponent.

This report's analysis regarding the issue of the time value of facilities capital payments does not simply point out that the time value is not zero. It shows that the risk-free rate should be used to calculate this time value. Facilities capital may receive a risk premium of 45 percent. However, this is conceptually distinct from the determination of the time value of money. In particular, it is incorrect to use the risk premium to calculate the time value of payment delay. Calculation of the return to facilities capital by compounding at an interest rate significantly above the risk-free rate would create errors equally large or larger than those generated by the current rule with compounds at a zero interest rate. Therefore, just as for the case of working capital discussed in Sec. 5, some sort of IRR approach which confuses the concepts of a risk premium and the time value of money would not be appropriate.

E. POLICY IMPLICATIONS

The major change suggested by the theoretical analysis of this subsection is that the rule for calculating facilities capital profit be modified to correctly account for the time value of money. Several other aspects of the policy possibly require some refinement or further analysis also. These will now be listed.

First, the normal rate of return suggested for equipment is incredibly high—it is 35 percent plus the treasury rate. Since the treasury rate has averaged 10 percent, this is approximately a 45 percent return. If the risk-free rate is 10 percent, this would correspond to an expected utilization rate of less than 0.25 for a risk-neutral firm. Thus, al-

though the analysis of Subsection B does not necessarily demonstrate that 45 percent is too high, it does suggest that further analysis is required. The same point applies as well to the return on buildings of 15 percent above the treasury rate, or approximately 25 percent.

Second, a related point is that the category of equipment may be much too broad. Equipment can include telephones, desks, and other office equipment, as well as state-of-the-art manufacturing equipment. It may be that one could justify a 45 percent return for the latter type of equipment, but it is hard to justify this return for general purpose office equipment. The regulation includes a qualitative directive to consider the type of equipment when deciding whether to award a higher or lower rate than the normal value. However, the "normal" rate is 45 percent. Thus, presumably a firm with a "normal" amount of office equipment and outmoded manufacturing equipment would be allowed a 45 percent return. One alternative would be to divide equipment into subcategories, such as office equipment, old machinery, state-of-the-art machinery, etc., and have a different normal value and range for each class. Another possibility would be to specify a much lower return for equipment but to allow the contracting officer to authorize one-time profit bonuses for firms when they purchase state-of-the-art manufacturing equipment that is required for a particular program.

Third, recall from Sec. 2 that the regulations actually label part of the return to facilities capital as a "cost" instead of as a "profit." This is the part equal to the treasury rate times the net book value of facilities capital. This has one small substantive effect. Progress payments are made on the fraction of the return labeled as a cost. This was ignored in the formal calculations of this subsection to simplify the notation. It would be straightforward to include this, however. Roughly speaking, 80 percent (100 percent) of the financing cost on the treasury rate portion of the return should be removed for fixed-price-type (cost-type) contracts. More fundamentally, however, there does not seem to be any good reason to artificially label a particular portion of the return to capital as a cost. The two major results of this policy appear to be to generate small amounts of confusion and to create the need for the DoD to use the phrase "all costs except the cost of money" in place of the phrase "all costs" in innumerable places in the regulations. Therefore, the regulations should be changed to include all of the return to facilities capital as part of profit in the weighted guidelines. The main effect this would have is that firms with fixed-price-type contracts would no longer receive progress payments on the treasury rate portion of the return to capital. However, one could simply adjust the facilities capital return upward a small

amount so that firms would be no worse off if objections were raised to this change. This change would therefore have no significant substantive effect. However, the goal of clarifying and simplifying the regulations is worthwhile in and of itself.

Fourth, note that this section has considered only the question of how to calculate an adequate return for facilities capital. However, it is clear that a major policy question in this area is how to stimulate firms to invest in cost-minimizing levels of facilities capital. Thus, a more general analysis that considers this question is required. For example, from the standpoint of adequate compensation, the policies of paying firms a large one-time bonus followed by lower rates and paying a constant intermediate rate are both equally good ways to compensate firms for purchasing state-of-the-art manufacturing equipment. However, there may be many other differences between the policies. Note that as the initial bonus becomes higher and subsequent payments become lower, the policy essentially becomes one of government ownership of facilities capital. Thus, the fundamental economic question may be to understand whether government ownership of facilities capital would be a good or bad idea. Thus, much more economic analysis of the entire issue of facilities capital is required and this is beyond the scope of this report.

F. VALUES OF A IMPLICIT IN THE CURRENT REGULATIONS

The current rule for calculating profit on facilities capital of type i is given by

$$(R_T + B_i)K_i \ell, \quad (11.15)$$

where R_T is the treasury rate and the other terms are as defined before. The proposed revision would use the rule

$$(R_F + A_i)K_i \left\{ \frac{(1 + R_F)^t - 1}{R_F} \right\}. \quad (11.16)$$

If the normal values of A_i were specified to be the same as for B_i (as given in Table 2.5), then the proposed revision would actually yield a greater profit for two reasons.

- (i) As explained in Sec. 7 the correct method for calculating the risk-free rate would perhaps yield a rate averaging 1-1/2 percent above the treasury rate.
- (ii) The term $[(1 + R_F)^t - 1]/R_F$ is greater than t , reflecting the fact that the correct rule compensates for the time value of money.

The purpose of this subsection is to simply calculate what values of A_i would yield the same profit on a contract of typical length as the current values of B_i . This calculation is interesting for two reasons. First, the resulting values of A_i can be interpreted as the implicit values for the FCRP in the current regulations. Second, in the absence of more empirical research these values might be a reasonable choice for a revised rule. They have the property that government's overall payment of profit would remain roughly the same. However, relative profit levels among contracts would change in a manner consistent with the correct rule. In particular, longer contracts would receive relatively higher profit. Therefore, firms would not be automatically penalized by accepting longer contracts.

To perform this calculation it will be assumed that the typical contract lasts three years. The treasury rate will be assumed to be 10 percent, consistent with the data from Sec. 2. Since the risk-free rate is assumed to average 1-1/2 percent above the treasury rate, it will be assumed to be 11-1/2 percent.

For any given value of B_i the corresponding value of A_i that generates the same profit is determined by setting Eq. (11.16) equal to Eq. (11.15). Substitution of the assumed values into this equation and solving for A_i yields

$$A_i = -0.026 + 0.893B_i \quad (11.17)$$

Note that the value of A_i is definitely lower than the corresponding value of B_i to compensate for the two effects identified above.

Now the minimum, maximum, and normal values of the FCRP for each type of capital can be calculated by substituting the values of B_i from Table 2.5 into Eq. (11.17). The resulting values of A_i are presented in Table 11.2.

Note that the risk premium for land is negative, because the current regulations choose B_i equal to zero but then underestimate the risk-free cost by using the treasury rate, which is 1-1/2 percent below the risk-free rate, and by ignoring the time value of delay.

Table 11.2
Values of A_i Implicit in the Current Regulations
(in percent)

Category	Normal Value, %	Allowable Range, %
Land	-2.6	(Must be -2.6)
Buildings	10.8	6.3 to 15.3
Equipment	28.7	15.3 to 42.0

G. THE ALTERNATIVE POLICY

Recall that regulations state that the negotiator may choose to calculate profit for facilities capital by giving the firm the treasury rate plus 2 percent of "cost minus G&A." This may be done for research and development firms or service firms that have low levels of facilities capital.

This policy appears nonsensical. If a firm does not use facilities capital then no return is required.

One possible justification could be an argument that current regulations generally estimate ω too low and offer too high a return on facilities capital. The average firm still receives adequate compensation. However, if this is true then firms with levels of facilities capital larger (smaller) than average receive compensation that is larger (smaller) than adequate. The obvious solution is to readjust the entire structure so that each separate aspect of the contract is priced properly for all contracts.

The regulations also allude to a possible justification based on a theory of cost misallocation. It is noted that an R&D contract performed by a manufacturing firm might well be allocated a share of facilities capital much larger than that actually used. This would not happen if the R&D contract was performed by an R&D firm. Thus, the same contract would receive higher profits if performed by the manufacturing firm. However, the solution to this problem is not to give the R&D firm an arbitrary increase in economic profit. The solution is to revise the cost allocation scheme of the manufacturing firm if this discrepancy is thought to be a problem.

12. ECONOMIC PROFIT

A. INTRODUCTION

The previous chapters have considered all possible categories of profit meant as reimbursement for economic costs that are not recognized as costs by the accounting system. This section considers profit meant as economic profit.

Subsection B describes one reason why the current regulations explicitly acknowledge paying positive economic profit. However, it is argued that this reason is probably invalid or at least requires much more careful justification. Subsection C then argues that there is probably a much more important reason to pay economic profit that the current regulations do not explicitly acknowledge. Finally, Subsection D explains how the payment of economic profit should be incorporated into the pricing rule.

B. PROFIT AS A REWARD FOR SPECIFIC OBSERVED ACTIONS

The regulations seem to contain some cases where negotiators are instructed to give firms positive economic profit if the negotiator observes the firm adopting certain behavior patterns that the DoD wishes to encourage. Thus, positive economic profit is paid as a pure reward for specified actions that can be observed by the negotiator.

An important point to note about such schemes is that the negotiator can never give a firm negative economic profit. The firm would rather not accept the contract. Thus, a scheme that attempts to reward behavior with economic profit invariably must reward a positive level of average economic profit. The worst performers will receive zero profit and better performers will receive positive profit. Thus, average economic profits will be positive. Implementation of such an incentive scheme has high costs.

The alternative to such a scheme would be to simply require firms to adopt the specified behavior as a precondition for giving them contracts. This is possible because the actions are by definition observable by the negotiator. Therefore, so long as all economic costs of the contract are reimbursed the firm will be willing to adopt the behavior.

It may well be that rewarding a firm with degrees of profit can allow a more flexible response than simply refusing to do business with the firm. Perhaps other justifications are possible in specific cases as well. In some cases, described below as incentive payments, it may be that they are actually intended to pay for some unrecognized cost. If this is true, the nature of the unrecognized cost should be clearly indicated and the item should be moved to the "other unrecognized costs" section of the regulations. If an incentive payment of economic profit is really intended, a careful theory of why the action cannot simply be required as a precondition for contracting needs to be explicitly articulated.

Investigating whether economically rational formal theories exist that could support such incentive payments is beyond the scope of this report. The purpose here regarding these items is simply to identify that current regulations seem to envisage this as one of the functions of profit and to identify the type of economic reasoning required to justify this use.

To conclude this discussion, four specific incentive functions of this type, which are mentioned in current regulations, will now be described.

1. Efforts to Control and Reduce Costs

A section of performance profit labeled "cost control" is devoted to identifying behavior patterns of contractors that are likely to yield lower or higher costs to the government.¹ The former are to be rewarded with higher profit and the latter punished with lower profit. For example, well-developed cost-estimating and tracking systems are to be rewarded. Similarly, evidence that the firm is attempting to reduce subcontracting costs by such methods as dual sourcing is to be rewarded.

Note that this profit is in addition to all costs. Thus, for example, suppose the firm hires one more engineer at a cost of \$1000 to track costs. The variable \bar{C} will include this cost. However, the cost-control section of profit policy regulations instructs the negotiator to give the firm a payment in addition to this cost. This is economic profit. Similarly, if the firm has a good record of cost control, the regulations instruct the negotiator to give the firm a payment in addition to all costs. This, too, is economic profit.

¹48 CFR 215.970-1,a,3,iii.

2. Poor Plant Management

The regulations state that "a significantly below normal profit value may be justified if reviews performed by the field contract administration offices disclose unsatisfactory management and internal control systems (e.g., quality assurance, property control, safety, security)."² Although this reference is contained in the management section, it is clearly different from the management effort question described in Sec. 11.

3. The Contractor Is Not Responsive to the Negotiator's Requests During Negotiation

The regulations seem to suggest that the negotiator can punish uncooperative firms by reducing their profit. It states that the negotiator should lower profits if "the contractor does not cooperate in the evaluation and negotiation of the proposal."³ Although the regulation is a little vague about what is meant by uncooperative (Is a firm that refuses to lower its price being uncooperative?), it seems to imply that the negotiator can lower profits if he feels that the firm has not openly and quickly supplied him with the information he requests. This regulation is included in the management section of performance profit but once again is clearly conceptually distinct from the management effort question described in Sec. 11.

4. Socioeconomic Programs

The regulations specify that "the contracting officer should also give consideration to the contractor's support of federal socioeconomic programs, such as small business concerns, small business concerns owned by socially and economically disadvantaged individuals, handicapped sheltered work shops, labor surplus areas, and energy conservation."⁴

This regulation is also included in the management section.

²48 CFR 215.970-1,a,3,ii,B.

³48 CFR 215.970-1,a,3,ii,B.

⁴48 CFR 215.970-1,a,3,ii.

C. PROFIT AS AN INCENTIVE TO INDUCE RENT-SEEKING BEHAVIOR⁵

1. Introduction

Suppose that profit policy on average compensated firms for exactly all their costs of production (including the cost of risk-bearing, capital, and unrecognized costs) but gave them no more. Although a firm would be willing to accept a defense contract under such a scheme, it would be totally indifferent as to whether it received the contract or not. However, now suppose that profit policy actually gave firms an economic profit over and above compensation for all their costs when they received a contract. Then firms would strongly prefer to receive contracts and would in fact compete for them. In particular, they would be willing to spend their own money on activities designed to help them win contracts. It is clear that two such ways of spending money are conducting independent research and development (IR&D) and spending money on bids and proposals (B&P). Thus, economic profit can be a prize for the firm that wins the right to perform a contract. The existence of such prizes can induce firms to spend money on IR&D and B&P in an attempt to win the prize.

To complete the argument it must be explained why the DoD does not simply directly fund all IR&D and B&P expenses. This will be considered below for each case separately. However, a number of general points about this process should be noted.

First, economists use the term "rent-seeking" to describe any situation where firms spend money in an attempt to compete for a prize. This explains the title of this subsection.

Second, although firms earn economic profit on the contracts they receive they are spending their own money on IR&D and B&P attempting to win the right to earn this economic profit. Thus, firms may not be earning overall profit. In fact, if entry is possible, in the long run firms must be earning zero economic profit overall or more entry would occur. Thus, the economic profit on contracts can be viewed as indirect compensation for expenses incurred before the contract is awarded.

Third, even in the long run the "conversion rate" of economic profit into IR&D and B&P expense is unlikely to be 100 percent. That is, \$1 of prizes is unlikely to generate \$1 of IR&D and B&P expense, because other methods of spending money to affect the probability of

⁵Much of this section is drawn from Rogerson (1989).

winning contracts exist. An important method is congressional lobbying. Thus, even if 100 percent of the economic profit is converted into rent-seeking expenditures of some sort, less than 100 percent will be the desired types of IR&D and B&P. A very significant fraction may be converted into undesirable types such as congressional lobbying. Furthermore, it may be that firms will spend relatively more on B&P expense and less on IR&D expenses than DoD would find optimal. The use of prizes, therefore, is not a perfect method to induce IR&D and B&P expenditures. However, it will be argued below that the alternative of directly funding these activities also has serious problems. Thus, creating prizes is a necessary component of the regulatory system.

Fourth, it may seem that the class of factors described in Subsection B is the same as those described in this subsection. After all, both are regulations that award positive economic profit as an incentive device. However, the items discussed in Subsection B are actually very different—profit was given if and only if a specified activity was observed. That is, profit was a direct payment for a directly observable activity. In this subsection profit on contracts is simply created. The firm has to do nothing in particular other than win the contract to receive the profit. Thus, the regulations described here rely on competition for the award to create desirable behavior. The regulations described in Subsection B rely on direct payment for observed behavior as an incentive to create desirable behavior.

Subsections 2 and 3 will now explain in more detail why there are problems with attempting to directly fund IR&D and B&P expense.

2. IR&D

The argument explaining why giving economic profit on contracts may be the best method for inducing firms to innovate will be given in three parts.

Part a. Prizes for innovation are required.

The argument of Part a is that the DoD is unable to directly purchase the innovative efforts of firms. Therefore, it must indirectly give firms the incentive to provide this effort by establishing rewards for successful innovation. This is true for two reasons.

First, there is a moral hazard problem. The amount of innovation produced is obviously only stochastically related to the amount of effort exerted. Furthermore, it is difficult to monitor the level of effort

a firm is exerting. "Exerting more effort" might amount to the following sorts of behavior.

- (i) Assigning the firm's best engineers to the project. Peck and Scherer (1962) particularly stress the importance of this issue and call it the "talent allocation" problem. They state

The highly talented technical and managerial personnel in a weapons firm affect the success or failure of programs to a degree rarely reflected in salary differentials. Since few if any companies are so well staffed that they can assign first-rate scientists, managers, and engineers to every project they undertake, important qualitative resource allocation decisions must be made.⁶

- (ii) Having management devote large amounts of time and effort to deciding which approaches and projects would be most likely to be successful.
- (iii) Keeping a research team together at the firm's own expense for periods of time when no business exists. Peck and Scherer (1962) also stress the value of a functioning research team.⁷

None of these is easily observable or measurable by the DoD. Therefore, the DoD's only alternative is to attempt to give firms an incentive to exert this effort by promising to reward successful innovation with prizes.

However, even if level of effort were totally observable, a second factor would still necessitate the use of prizes. This is that firms are very likely to possess private information about which sorts of projects are more likely to yield the kind of results of most value to the DoD. To illustrate this idea, suppose that exerting effort consisted only of spending money and the DoD could exactly monitor the amount of money spent. Furthermore, assume that two possible projects exist for a firm to explore—projects A and B. Assume as well that the DoD can also monitor whether money is spent on project A or B. Therefore, the DoD could simply directly order the firm to exert given levels of effort on each project and directly monitor that this occurred. However, now suppose as well that project A is likely to produce high benefits to the DoD but will yield very few commercial spinoffs for the firm. Project B is the reverse. It is likely to produce very low benefits for the DoD but will yield a number of useful ideas

⁶Peck and Scherer (1962), p. 501. Also see pp. 501–507 for further discussion.

⁷Pp. 180–181.

that the firm can use in its commercial business. Furthermore, suppose that because of its greater technical expertise only the firm is aware of this fact. Both projects appear to be similar to the DoD. If the firm were simply hired to perform research (which is possible by assumption because research effort is directly monitorable), the firm would have an incentive to recommend project B. To give the firm an incentive to choose project A, the DoD must pay the firm not according to the amount of effort it exerts but instead according to the value of the ideas produced. That is, successful innovations must be rewarded with some sort of prize.

Another way of stating this second point is that an optimal research program should be somewhat decentralized so that firms can make decisions based upon their private information. However, when delegating some decisionmaking to firms, the DoD must simultaneously provide the firms with incentives to make the decisions that are best from the DoD's perspective. Establishing prizes for innovation accomplishes this. As an example, companies will often fund prototypes for a particular system that they believe has great potential even if no one in the DoD at that time yet agrees.⁸ Thus, when there are prizes for successful innovation, firms have an incentive to use their own funds if necessary to pursue research projects that they strongly believe will eventually yield results of great value to the DoD.

Part b. A regulatory structure that directly provides larger prizes for higher-quality innovations is not possible.

The argument of Part a does not by itself establish the regulatory principle that defense firms should earn positive profits on production contracts. In principle, government could commit to R&D incentive contracts of the form $w(x)$ where $x \in X$, X is the space of all possible innovations, and $w(x)$ is the wage the contractor will receive if the innovation x results. Then, production contracts could be priced to yield zero economic profit, and the payment of higher wages to more valuable innovations would provide the incentive for innovation. Furthermore, $w(x)$ could be chosen so firms were just willing to perform the R&D and thus earned zero economic profit in the R&D phase as well.

However, it is clear that the transactions costs of writing out a legally enforceable, objectively verifiable contract describing all possible innovations and the price that would be paid for each one would be

⁸For example, a number of prototype predecessors of the F-16 and AH64 were privately funded by firms. See Smith et al. (1981), pp. 84 and 155-158.

prohibitively costly if not impossible for all but the most trivially simple R&D projects. Some R&D occurs within well-defined programs with fairly well-defined objectives. Even in these cases it seems unlikely that the DoD could provide a legally enforceable contract covering all possible design improvements. However, a large fraction of firms' R&D is directed toward identifying more basic new ideas and concepts for weapons development. As explained in Part a, the R&D process is somewhat decentralized to allow firms to use their own private information in deciding which avenues of R&D to explore. To sign a legally enforceable contract directly rewarding the results of this more far-ranging basic R&D would literally require government to list the universe of possible innovations and the prize attached to each one. This is obviously impossible.

One other option would be for government to simply announce that it would evaluate the quality of each new innovation and award a prize based on the evaluated quality. One might imagine creation of a "DoD prize panel," which annually assessed the results of all firms' efforts and awarded prizes accordingly. Such a scheme would probably be totally infeasible because of the subjectivity of any such evaluation. Firms would all claim that their research was unfairly evaluated and one could imagine endless congressional investigations into such a scheme. (It might also be politically difficult to award large prizes.)

Thus, transactions costs prevent the writing of legally enforceable contracts that directly reward innovation. The option of relying on government to evaluate each innovation and assign it a "fair" reward based on its quality is too subjective to work. Therefore, it is not possible to directly pay larger prizes for higher-quality innovations.

Part c. Contracts that provide economic profit on production contracts will provide prizes for good innovations and, to some extent, provide larger prizes for more important innovations.

The obvious objectively verifiable signal of whether a firm has created a successful new weapons design is whether the DoD chooses to purchase it. Thus, a regulatory system could create prizes for innovation by guaranteeing that any firm that wins a contract will earn positive economic profit. In such a system, firms that can successfully generate ideas good enough to be adopted by the government would receive prizes in the form of economic profit.

Furthermore, if profit is awarded approximately as a percentage of cost (i.e., the profit earned on a system doubles if the system is twice as expensive), this might in a very rough sense also tend to award

larger prizes for better innovations for two reasons. First, systems that prove to be useful will be purchased in larger quantities. Second, there is probably some sense in which a \$30 billion project is more important to government than a \$30 million project.

Finally, note that such a system will also provide incentives for the firm to continue to innovate and improve its product even after it is initially adopted, because it can guarantee more sales (and thus more profit) by improving the system. Constant upgrading of existing systems is a very important part of the overall innovative effort in defense procurement, so this is an important point.

3. B&P Expense

Firms are required to spend significant amounts of money preparing detailed proposals in response to government solicitations for bids on various contracts. Because the items being purchased are one of a kind and could be potentially produced using a variety of technical approaches and have a variety of final performance characteristics, firms cannot simply submit a dollar bid. Rather, they must describe in great detail factors such as

- (i) The technical approach they will follow,
- (ii) The experience of the research team that will be assigned to the project,
- (iii) The identity of potential subcontractors, and
- (iv) Anticipated performance parameters.

The key point is that government needs this information to choose the best supplier. Thus, at least some level of bid and proposal expense is desirable and necessary.

The DoD does not, however, directly reimburse firms for their B&P expenses, because firms would be willing to spend unlimited amounts of money competing for production contracts if their expenses were reimbursed. Similarly, the DoD wants only well-qualified firms to compete for contracts. If a firm must spend its own money preparing a bid it will do so only if it feels it has a realistic chance of submitting the best proposal. However, if it knew it could obtain government funding for preparing its bid, it would be much more likely to waste money on very speculative bids. Thus, direct government reimbursement of B&P expense would result in qualified firms spending too much on their proposals and large numbers of unqualified firms also spending money on proposals.

D. INCORPORATING ECONOMIC PROFIT INTO THE PROFIT RULE

Any profit rule calculated to reimburse a firm for economic costs necessarily has the property that the firm has no incentive to artificially divide a single two-year contract into two one-year contracts to receive full payment for part of its production sooner, because the time value of delay is correctly accounted for. Although the firm's payments are delayed by using a single two-year contract, the financing profit is increased to appropriately reflect this.

This lack of arbitrage opportunities is a desirable property because it removes incentives for contractors to distort contracting arrangements in attempts to "game" the profit rules. The rule for awarding economic profit should therefore be structured to maintain this desirable feature. A natural method for doing so is described below.

Suppose it is decided to pay the firm e percent of expected costs as economic profit. Then, a rule that creates no arbitrage incentives can be created by assuming that the firm should be paid e percent of cost as the cost is incurred. Delay of the payment is then accounted for at the risk-free rate. In particular, then, the economic profit on period t costs would be equal to

$$eE(\tilde{C}_t) + eE(\tilde{C}_t) \left[(1 + r_F)^{n+1-t} - 1 \right], \quad (12.1)$$

where the first term is the amount that would have been paid had the payment occurred in period t , and the second term is the value of delay. Summation over t and reorganization yields a total profit of

$$e \{ E(\tilde{C}) + F \}. \quad (12.2)$$

Thus, the profit is calculated as e percent of the financing costs as well as the production cost, to prevent arbitrage opportunities. Since the value of F must already be calculated by the contracting officer, the rule in Eq. (12.2) is costless to implement.

E. POLICY IMPLICATIONS

The major policy implication of this subsection is that it may well be optimal for the DoD to purposely give positive economic profit on contracts to create prizes for innovation (and to a lesser extent for B&P

activity). In particular, the optimal level of *economic* profit awarded by profit policy may well be greater than zero.

The important question this analysis raises is "What should the rate of economic profit be optimally set at?" This is beyond the scope of this report. Two critical issues in answering this question are the following. First, the relationship between the stated economic profit in profit policy and the actual economic profit that firms earn must be determined. One might refer to these, respectively, as *ex ante* and *ex post* profit. They obviously could differ, and firms' incentives to innovate will be affected by *ex post* profits, not *ex ante* profits. One piece of evidence on the relationship between *ex post* and *ex ante* profits is in Rogerson (1989). The *ex post* profits of prime contractors on the major aerospace systems were directly estimated. The average economic profit rate was found to be 4.6 percent of cost, which is triple the *ex ante* rate of 1.5 percent of the current policy.⁹

The second issue regards the size of the conversion rate between *ex post* profits and IR&D and B&P expenditures of firms. That is, if economic profit was increased by \$1, what fraction of this dollar would be spent on IR&D and B&P? It is possible to estimate the average conversion rate of *ex ante* profits. The defense industry as a whole appears to spend approximately 1.08 percent of allowable cost on contractor-funded IR&D and B&P.¹⁰ The *ex ante* profit rate of 1.5 percent is approximately 150 percent of that. The industry-wide average conversion ratio thus appears to be 66.6 percent. This, however, is probably not a very useful number for policy purposes. Detailed analysis of the above two issues needs to be conducted sector by sector.

Aside from this major issue, the analysis of this section has three smaller policy implications. First, more careful thought needs to be devoted to the question of whether profit incentives as rewards for specific observable actions should play any role in profit policy and why. As explained above, there is a very compelling argument that all of these schemes should be eliminated. Namely, so long as firms are being fairly compensated for all of their costs there is no need to pay them economic profit to make them perform observable actions. Therefore, these schemes should be eliminated unless some good reason can be found to retain them.

⁹The figure of 1.51 percent will be derived in the next section.

¹⁰DoD (1985a), Appendix I, Volume II.

Second, as explained in Subsection D, economic profit should be awarded as a percentage of cost plus financing cost to remove arbitraging opportunities.

Third, the function of inducing innovation could probably be improved by making the level of economic profit awarded on particular contracts more responsive to the need for and importance of innovation for the product line in question. It is clearly the case, for example, that more innovation is required to produce a state-of-the-art fighter than a standard issue rifle. If this is the case, then different levels of economic profit should be awarded. This suggests two possible regulatory approaches. First, it might be possible for the regulations to specify different normal values of economic profit depending on the type of product. Second, the regulations should specifically state that contracts requiring larger (smaller) amounts of IR&D and B&P expense before the award of the contract should receive a profit that is larger (smaller) than normal.

An example of how sector-specific profit rates could be designed to provide differential innovation incentives across sectors will now be described. Suppose all sectors are initially assigned the same normal value of e . The proposed revision will result in the same overall amount of economic profit being paid. However, profit will be shifted away from sectors where innovation is less important and toward sectors where innovation is more important. The importance of innovation will simply be measured by calculating each sector's current expenditures on IR&D as a percentage of total costs. It will be assumed that innovation is more important in sectors that currently have larger percentages of their expenditures devoted to IR&D. This is obviously not a totally adequate measure. For example, it may be that there is a great need for innovation in some sectors where very little is currently being spent on IR&D. DoD policymakers could presumably fine-tune the various profit rates. Table 12.1 displays IR&D and B&P expense as a percentage of allowable cost for eight broadly defined sectors of the defense industry. Note that the amount of money spent on IR&D and B&P varies dramatically across these sectors. Let α_i denote the value for sector i in Table 12.1.

Table 12.2 gives each sector's cost as a fraction of all sectors' costs. Let s_i denote the share of sector i . Now let e_i denote the normal percentage return for sector i .

The normal returns will be chosen to satisfy two properties. First, they should produce the same amount of profit for the industry as a

Table 12.1**IR&D and B&P Expenses as a Percentage of Allowable Cost by Defense Sector**

Sector	Percent ^a
All sectors	1.08
Aircraft	1.64
Missiles	0.67
Ships	0.04
Other weapons	0.52
Electronics	1.37
Other equipment	1.71
Services	0.13

^aCalculated using 1983 data from DoD (1985a) Appendix I, Volume II. See this reference for a description of the sectors. Data on the "vehicles" and "ammunition" sectors were not reported in this source because the small number of firms would have revealed individual company data.

Table 12.2**Allowable Cost by Sector as a Share of Total Allowable Cost**

Sector	Normal Value ^a
All sectors	1
Aircraft	0.354
Missiles	0.224
Ships	0.083
Other weapons	0.082
Electronics	0.209
Other equipment	0.006
Services	0.042

^aCalculated from DoD (1985a), Appendix I, Volume II. Data for the year 1983 are used.

whole as the current rule of applying e uniformly. Formally, this means that the values of e_i should satisfy¹¹

¹¹Equation (12.3) requires the reasonable assumption that financing costs are the same fraction of costs across sectors.

$$\sum s_i e_i = e . \quad (12.3)$$

Second, sectors that spend more on IR&D and B&P should receive proportionately larger returns. Formally, this means that there exists some constant k such that

$$e_i = k \alpha_i \quad (12.4)$$

for every i . Substitution of Eq. (12.4) into Eq. (12.3) yields

$$k = \frac{e}{\sum \alpha_i s_i} . \quad (12.5)$$

Values from Tables 12.1 and 12.2 can be substituted into Eq. (12.5) to yield

$$k = 0.927e . \quad (12.6)$$

Substitution of Eq. (12.6) into Eq. (12.4) yields

$$e_i = 0.927e \alpha_i . \quad (12.7)$$

Therefore, the normal value of e_i is calculated by multiplying the values of α_i in Table 12.1 by $0.927e$. The proposed revision in Sec. 14 will use this method to calculate values of e_i for a particular e .

This example calculation is obviously not totally satisfactory because it uses such a crude measure of the importance of innovation. Nonetheless, it illustrates the point that even a regulation that considered only eight broadly defined sectors and specified a normal level of profit for each might provide considerably more accurate targeting of prizes to areas where they are needed.

13. CALCULATION OF THE ECONOMIC PROFIT RATE IMPLICIT IN THE CURRENT REGULATIONS

A. INTRODUCTION

Although Sec. 12 was able to identify the important economic factors that should influence the size of the economic profit rate offered by the regulations, it is beyond the scope of this report to conduct empirical studies that might actually permit the estimation of the correct rate. Thus, this report will not prescribe a correct level of economic profit in its proposed revision. Instead, this section will determine the level of economic profit the current regulations are implicitly currently providing. This rate will be used in the proposed revision presented in Sec. 14.

This calculation is performed as follows. First, the profit as a percentage of expected cost that the current regulations yield on a typical contract is calculated. Second, the profit as a percentage of expected cost yielded by the proposed revision of profit policy suggested by this report is calculated for the four categories of profit meant as reimbursement for economic costs—contract risk, working capital, other unrecognized costs, and facilities capital. For this calculation the correct levels (as determined by this report) of the risk-free rate and normal value of other unrecognized costs are used. The levels of the risk premiums are set equal to those implicitly embedded in the current regulations. Then, third, the second profit value is subtracted from the first.

The resulting profit (expressed as a percentage of expected cost) can be interpreted as the economic profit rate that the current regulations are actually paying. It is shown that the regulations appear to provide an economic profit of 1.51 percent of expected cost to a firm with a typical mix of cost-type and fixed-price-type contracts. However, most of this profit is derived from cost-type contracts. The regulations provide economic profit of 4.06 percent of expected cost on cost-type contracts but only 0.56 percent of expected cost of fixed-price-type contracts.

There does not appear to be any good theoretical reason to pay larger levels of economic profit on cost-type contracts than fixed-price-type contracts. Thus, in the absence of such a theory, a correct regulation should probably not distinguish between contract type in awarding

economic profit. To maintain the same overall level of economic profit, the correct regulation should therefore specify a normal value of economic profit of 1.62 percent of expected cost for all types of contracts.¹

B. ASSUMPTIONS

To calculate the profit levels that would "typically" occur, one must make assumptions regarding what "typical" parameter values are. This subsection will describe the assumptions used in this section.

Of course, the normal values will be used in all calculations when the regulations cite a normal value and allowable range. As has been previously assumed in this report, G&A cost will be taken to equal 12 percent of cost including G&A.² The typical contract will be assumed to last three years.³ Section 2 showed that the average value of the treasury rate has been 10 percent. This value will be used here. In accord with Sec. 7, it will be assumed that the average value of the risk-free rate equals 11.5 percent, which is 1.5 percent above the average treasury rate. Finally, it will be assumed that the typical pattern of cost incurrence is uniform. The approximation derived in App. D will be used to calculate F.

It will be necessary to know the ratio of the net book value of facilities capital to expected cost broken down by land, buildings, and equipment to perform the calculation. From a very large sample of defense firms *DFAIR* (DoD, 1985a, Appendix I) found that in 1983 these ratios were as shown in Table 13.1.

Table 13.1

**Net Book Value of
Facilities Capital as
a Fraction of Cost**

Equipment	0.0730
Buildings	0.0441
Land	0.0091
Total	0.1262

¹The value is 1.62 percent instead of 1.51 percent because of a technicality involving the deflation factor. This will be explained in Subsection E.

²Recall that this figure is from Meyers et al. (1985), p. 2.9.

³DoD (1985a), p. IV.15.

It will be assumed that these values hold for the typical firm.

Finally, to calculate profit for the defense industry as a whole, information on the fraction of fixed-price-type and cost-type contracts will be required. In 1983, *DFAIR* (DoD, 1985a, Appendix I) found that 28.5 percent of the dollar value of the DoD's purchases were on cost-type contracts and 71.5 percent were on fixed-price-type contracts. These values will be used in this section.

C. THE CURRENT REGULATIONS

The profit as a percentage of cost will first be calculated for a firm fixed price contract under the current regulations. Performance profit equals

$$0.0352E(\tilde{C}) \quad (13.1)$$

from Table 2.5. Contract risk profit equals

$$0.0264E(\tilde{C}) \quad (13.2)$$

from Table 2.5. Facilities capital profit is given by

$$\{0.1262R_T + 0.15 \times 0.0441 + 0.35 \times 0.0730\}E(\tilde{C}) \quad (13.3)$$

from Table 2.5 and Table 13.1, where R_T denotes the treasury rate. Substitution of $R_T = 0.1$ into Eq. (13.3) yields

$$0.0448E(\tilde{C}) . \quad (13.4)$$

Finally, working capital profit is given by

$$(1 - \alpha)L(\ell)R_T E(\tilde{C}) . \quad (13.5)$$

Reference to Table 2.6 reveals that $L(\ell) = 1.15$. Substitution of this value, $\alpha = 0.8$, and $R_T = 0.1$ into Eq. (13.5) yields

$$0.0230E(\tilde{C}) . \quad (13.6)$$

Summation of the four components in Eqs. (13.1), (13.2), (13.4), and (13.6) yields

$$0.1294E(\tilde{C}) \quad (13.7)$$

Thus, a typical firm fixed price contract would receive a profit equal to 12.94 percent of expected cost.

A similar calculation can be performed for a cost plus fixed fee contract. The contract risk profit is reduced to 0.44 percent of expected cost and no profit for working capital is received. The resulting profit is

$$0.0844E(\tilde{C}) \quad (13.8)$$

or 8.44 percent of expected cost.

Since 71.5 percent of a typical firm's costs are incurred on fixed-price-type contracts, the levels of profit for a firm with a typical mix of contracts can be calculated as the weighted average of the firm fixed price and cost plus fixed fee levels using weights of 0.715 and 0.285. The resulting profit is 11.66 percent of expected cost.⁴

Table 13.2 presents all of these results for the case of a firm fixed price contract, cost plus fixed fee contract, and for a firm that had 71.5 percent of its costs incurred under the former type and 28.5 percent of its costs incurred under the latter type.

Table 13.2
Profit as a Percentage of Cost Under the
Current Regulations

Category	Firm Fixed Price	Cost Plus Fixed Fee	All Contracts
Performance	3.52	3.52	3.52
Risk	2.64	0.44	2.02
Working capital	2.30	0	1.64
Facilities capital	4.48	4.48	4.48
Total	12.94	8.44	11.66

⁴In reality some fixed-price-type contracts are FPI and some cost-type contracts are CPI. Ignoring this probably generates very little error. Furthermore, the two errors would tend to cancel one another.

D. ECONOMIC PROFIT IN THE CURRENT REGULATIONS

This subsection will first calculate the level of profit meant as reimbursement for economic costs that the proposed revision of profit policy would award on a typical contract. It will then subtract this from the profit levels calculated in Subsection D to yield the economic profit level implicit in the current regulations.

First, consider a firm fixed price contract. The normal payment for contract risk is

$$0.0370E(\tilde{C}) \quad (13.9)$$

from Table 6.4. The value of F is given by

$$\frac{\ell}{2} \times R_F \times E(\tilde{C}) , \quad (13.10)$$

which equals

$$0.15E(\tilde{C}) \quad (13.11)$$

for the values assumed by this section. The cost of working capital is given by

$$(1 - \alpha)(1 + \omega)F . \quad (13.12)$$

Substitution of Eq. (13.11) and the assumed values for α and ω into Eq. (13.12) yields

$$0.0357E(\tilde{C}) . \quad (13.13)$$

Other unrecognized costs are assumed to have a normal value of 0.55 percent of expected costs. Therefore, the profit paid on a normal contract will be

$$0.0055[E(\tilde{C}) + F] \quad (13.14)$$

according to Eq. (10.8). Substitution of Eq. (13.11) into Eq. (13.14) yields

$$0.0063E(\tilde{C}) . \quad (13.15)$$

The profit paid on facilities capital will be assumed to be the same as that under the current regulations,

$$0.0448E(\tilde{C}) . \quad (13.16)$$

That is, the risk premiums implicitly used by the current regulations will be assumed to be correct.⁵ The total of Eqs. (13.9), (13.13), (13.15), and (13.16) equals

$$0.1238E(\tilde{C}) . \quad (13.17)$$

The first column of Table 13.3 presents these values.

Now consider a cost plus fixed fee contract. The profit for contract risk and working capital is zero. The profit for other unrecognized costs and facilities capital is exactly the same as for the fixed-price case. However, now the deflation factor must be applied to account for the fact that progress payments are made on profit. The formula is given by Eq. (9.5). Substitution of the assumed values into Eq. (9.5) yields

$$D = 0.8575 . \quad (13.18)$$

Thus, the profit calculated above must be deflated by multiplying by 0.8575 or, equivalently, 0.1425 of the above profit must be subtracted. This equals⁶

$$0.0073E(\tilde{C}) . \quad (13.19)$$

The sum of all five of these categories equals

$$0.0438E(\tilde{C}) . \quad (13.20)$$

The second column of Table 13.3 presents all of these values.

⁵Recall that these implicit values were calculated in Sec. 11, Subsection F.

⁶ $0.1425 \times 0.0511 = 0.0073$.

Table 13.3
Economic Profit as a Percentage of Cost
Under the Current Regulations

Category	Firm Fixed Price	Cost Plus Fixed Fee	All Contracts
Risk	3.70	0	2.65
Working capital	3.57	0	2.55
Other unrecognized costs	0.63	0.63	0.63
Facilities capital	4.48	4.48	4.48
Deflation	0	(0.73)	(0.16)
Total	12.38	4.38	10.15
Total from current regulations	12.94	8.44	11.66
Economic profit ^a	0.56	4.06	1.51

^aThis is determined by subtracting the "total" row from the "total from current regulations" row.

As in the previous subsection, the values of profit for a firm with a typical mix of fixed-price and cost-type contracts is calculated by adding 0.785 of the fixed-price column and 0.215 of the cost-type column. These results are presented in the third column of Table 13.3.

The calculation of economic profit rates by contract type and for the defense industry as a whole is now straightforward. The row labeled "total from current regulations" in Table 13.3 presents the profit rates yielded by the current regulations as presented in Table 13.2. If one subtracts the correctly calculated profit meant as payment for all economic costs from this, the remainder must be economic profit. The bottom row of Table 13.3 presents this value.

Therefore, the current regulations provide an economic profit of 1.51 percent of expected cost for the defense industry as a whole. However, very different rates are provided for fixed-price-type and cost-type contracts. Firm fixed price contracts receive 0.56 percent economic profit and cost plus fixed fee type contracts receive 4.06 percent economic profit.

There are two reasons for this great difference in economic profit. First, the current regulations incorrectly pay cost plus fixed fee contracts a profit for risk-bearing. The proposed revision correctly labels this as economic profit. Second, the current regulations undercompensate the firm for working capital because (i) the treasury rate is too low, (ii) the length factor is too low, and (iii) no risk factor is included. Thus, for the case of fixed-price contracts, economic profit is reduced by this undercompensation. However, there is no such

reduction for cost-type contracts, since they receive 100 percent progress payments.

E. ECONOMIC PROFIT IN THE PROPOSED REVISION

There does not appear to be any good theoretical reason to pay larger levels of economic profit on cost-type contracts than fixed-price-type contracts. Rather, this feature of the current policy seems to simply be the result of conceptual errors on the part of policymakers concerning how to calculate economic costs on a cost-type as opposed to a fixed-price-type contract. Therefore, in the absence of any such theory, the best policy recommendation appears to be to choose the same economic profit rate on both contract types.

For the proposed revision to continue to provide the same level of profit across the defense industry as a whole (i.e., 11.66 percent), this common economic profit rate should be set equal to 1.62 percent of expected costs.⁷

Table 13.4 presents profit as a percentage of expected cost by component for such a policy. The effect of choosing the same level of economic profit is dramatic. Comparison to Table 13.2 shows that profit paid on firm fixed price contracts is raised by approximately 1 percent whereas that on cost-type contracts is lowered by almost 3 percent.

Table 13.4
Profit as a Percentage of Cost Under the
Proposed Revision

Category	Firm Fixed Price	Cost Plus Fixed Fee	All Contracts
Risk	3.70	0	2.65
Working capital	3.57	0	2.55
Other unrecognized costs	0.63	0.63	0.63
Facilities capital	4.48	4.48	4.48
Economic profit	1.62	1.62	1.62
Deflation factor	0	(0.96)	(0.27)
Total	14.00	5.77	11.66

⁷The rate is not 1.51 percent because the deflation factor is applied to the economic profit on cost-type contracts. Therefore, slightly more than 1.51 percent must be paid to actually increase the profit paid across all contracts by this amount.

14. A SUMMARY OF THE IMPLICATIONS FOR IMMEDIATE CHANGES IN PROFIT POLICY

A. INTRODUCTION

This report has established an economic framework for analyzing profit policy by clearly describing the types of functions that profit is meant to perform and then using simple economic models to investigate how each function should be performed. As described in the introduction, this report does not provide a complete prescription for the form of an optimal regulatory policy for two reasons. First, the report has ignored four important issues described in the introduction. Thus, a somewhat idealized "base case" is analyzed. Second, even within the base case this report was not always able to unambiguously state what the level of a given component of profit should optimally be. Often, it simply identified the form that an optimal profit rule should take given some measurable parameters of the environment. It thus establishes a future research agenda of generalizing the base case analysis to include the four excluded issues and to perform the empirical analysis necessary to estimate the various parameters that appear in the correct rules.

However, the analysis here also provides a surprising amount of immediate guidance for the structure of profit policy. This section summarizes and gathers together the various implications for immediate change in profit policy rules contained in this report. The proposed revision specifies that the level of the risk-free rate be determined as suggested by Sec. 7. The level of the normal value for unrecognized costs is set equal to the value suggested by Sec. 10. The levels for the risk premiums for contract risk and facilities capital risk and the level of economic profit are set equal to the rates that the current regulations were shown to implicitly use. The result is a set of regulations with the economically correct form and levels of reimbursement determined largely by using parameter estimates implicit in the current regulations. These changes could be implemented without further theoretical or empirical analysis.

I am not necessarily recommending that these changes be immediately instituted. It would probably be useful to understand the theoretical considerations that arise when the base case is generalized to consider the four issues ignored in this report. In particular, the issue of cost minimization should probably be carefully considered.

Furthermore, empirical research could probably shed some light on reasonable parameter values for the correct policy. Finally, it may be that the current policymakers in charge of profit policy regulations would revise some of the parameter estimates implicit in the current policy if they were to adopt the economic framework for analysis suggested here. Input from all these factors should be included in any major revision.

Therefore, the major reason for summarizing the implications for change contained in this report is simply to provide a clear and simple summary of some of its major themes. Nonetheless, I do believe that if even greater change was impossible or would be very long in coming, the adoption of these changes would constitute a significant improvement in current regulations.

Subsection B discusses some general issues that arose in the report which need to be discussed to describe the suggested revision. Subsection C describes how the risk-free rate should be determined. (Since this would not be a formal part of the profit policy regulations it is described separately.) Then Subsection D describes the proposed revision.

B. GENERAL ISSUES

1. Uniform Cost Incurrence

To calculate financing cost, it was suggested that a simplified formula (depending only on ℓ and $E(\tilde{C})$) be presented as well as the correct formula. The simplified formula would be used for contracts below some dollar/length threshold. The simplified formula is determined by calculating the correct financing cost given a "typical" pattern of cost incurrence.

For the purposes of the following revision, it will be assumed that the typical pattern of cost incurrence is uniform. Obviously, this issue should be investigated before actually instituting a change in the regulations. Apparently the *DFAIR* authors (DoD, 1985a) constructed a typical model of cost incurrence based on analysis of actual contracts, although the detailed model was not published as part of the final report. Perhaps this model is available in unpublished form. It obviously could simply be reconstructed if necessary.

Recall that a greatly simplified rule for calculating working capital cost for the uniform case was derived by ignoring the effects of compounding. Furthermore, the approximation was quite good for typical cases. Therefore, this will be used in the proposed revision.

2. "Cost Minus G&A" as the Base Cost

Recall that current regulations calculate profit for all noncapital components as a percentage of "cost minus G&A cost." Since G&A is approximately 12 percent of total cost including G&A, one can convert a percentage described in the regulations to a percentage of total cost by multiplying by 0.88. To convert in the other direction, one multiplies by 1.14.

The reason for excluding G&A from the base cost must involve a theory of incentives for cost minimization. This is beyond the scope of this report.

The analysis here was carried out calculating percentages of all cost including G&A because this was notationally much less cumbersome. To minimize confusion, the proposed revision will also therefore be described using percentages of cost including G&A cost. However, one can convert any of these percentages to percentages of cost excluding G&A by multiplying by 1.14. As stated above, this report has nothing to say on the question of which method is preferable.

C. THE RISK-FREE RATE

The risk-free rate should be calculated as described in Sec. 7. The term "risk-free rate" is probably not suitable for the regulations. Therefore, for this description it will be called the "cost of funds rate." However, it will continue to be denoted by R_F in the formulas that follow.

The legislation and regulations implementing the calculation and issuance of this rate would not be part of the profit policy regulations. The profit policy regulations would simply instruct the contracting officer how to calculate profit given the current value of the cost of funds rate. Therefore, the necessary legislation and regulations will be described separately in this subsection. Subsection D will describe the revised profit policy regulations.

Legislation that instructs the GAO or Treasury Department to calculate and issue a "cost of funds premium" should be passed. This would be defined as the premium above the LIBOR that typical large defense contractors have paid for their short-term borrowing over the past five years. The legislation would also instruct the issuing authority to periodically (perhaps every two years) recalculate the premium.

Then, separate DoD regulations would establish an administrative group to calculate the cost of funds rate and issue it twice per year,

once to apply for January through June and once to apply for July through December. The rate would be calculated according to the following formula.

$$R_F = k + \sum_{t=1}^{12} s_t L_t , \quad (14.1)$$

where the s_t are nonnegative weights that sum to one given by

$$s_t = \frac{t}{\sum_{i=1}^t i} , \quad (14.2)$$

where k is the current value of the cost of funds premium, and L_t is the LIBOR futures rate for delivery t quarters in the future published on the last business day preceding the month of issue (i.e., the last business day of December for the January–June rate and the last business day of June for the July–December rate).

Note that the DoD calculation would be totally mechanistic. The only discretion and judgment exercised in the calculation of the cost of funds rate would be by the authority that calculates and issues the cost of funds premium. However, even for this calculation, the legislation is specific enough that very little discretion is allowed.

D. THE PROPOSED REVISION OF PROFIT POLICY

The proposed revision would calculate profit in six components. They will each be described in turn.

1. Contract Risk

The regulations should first instruct the contracting officer to estimate a risk parameter, ω . As explained in Sec. 5, the current regulations imply the following normal value and allowable range for ω .

Table 14.1

**Values of ω
(in percent)**

Normal	3.70
Allowable range	2.29 to 5.10

The profit for contract risk would then be calculated according to the formula

$$\pi = \gamma \omega E(\tilde{C}) , \quad (14.3)$$

where γ is the cost-sharing ratio and $E(\tilde{C})$ is the expected contract cost.

2. Working Capital

The cost of working capital is calculated according to the formula

$$\pi = (1 + \omega)(1 - \alpha)F , \quad (14.4)$$

where ω is the risk premium calculated in Component 1, α is the progress payment rate, and F is the risk-neutral financing cost. Perhaps F would be termed the "total financing cost" in the regulations.

For contracts that receive a flexible progress payment rate calculated by the Cash IV program, the calculation of working capital is closely related to the calculation of the flexible progress payment rate for two reasons. First, the progress payment rate used in Eq. (14.4) should be the flexible rate. Second, the data used to calculate the flexible rate also permit the calculation of F . Therefore, the regulations should require that firms wanting flexible progress payments submit the required data as part of their proposal. The Cash IV program would then simultaneously determine both a flexible progress payment rate and a value for F . The current cost of funds rate would be used in the calculation.

For contracts that will not receive a flexible progress payment rate, the following procedure should be used to calculate F . On contracts above some dollar/length threshold, firms should be required to estimate expected cost incurrence and delivery dates (when there are multiple deliveries) by month. Then a computer program should be available that automatically calculates the correct value of F using the perfectly correct formula and the current cost of funds rate. The regulations should simply reference the program. For contracts below the threshold the simplified formula

$$F = R_F \frac{\ell}{2} E(\tilde{C}) \quad (14.5)$$

should be used. This formula should be explicitly included in the regulations.

Two possible small alterations to this policy should be noted. First, it may be that policymakers will find it relatively costless for firms to develop lag and float information. In this case the regulation might require these data on all contracts above the dollar/length threshold regardless of whether flexible progress payments are applied for. Second, if the effect of lags and floats is found to be significant, the simplified formula in Eq. (14.5) might be adjusted to reflect the effect of lags and floats on a typical contract.

Finally, note that this rule should apply to all contracts. In particular, the current special treatment of fixed-price contracts that receive no progress payments should be discontinued.

3. Facilities Capital

The "cost of money" element calculated by applying the treasury rate to the book value of facilities capital should be relabeled as an element of profit and included in the weighted guidelines. The following formula should then be used to calculate facilities capital profit. Capital should be divided into three categories—land, buildings, and equipment. The profit for category i capital is given by the formula

$$\pi_i = (R_F + A_i)K_i \left\{ \frac{(1 + R_F)^i - 1}{R_F} \right\}, \quad (14.6)$$

where A_i is the risk premium for capital of type i and K_i is the net book value of capital of type i . The normal and allowable ranges of A_i are given by Table 14.2.

Table 14.2

**Values of A_i
(in percent)**

Type of Capital	Normal Value, %	Allowable Range, %
Land	-2.6	(Must be -2.6)
Buildings	10.8	6.4 to 15.3
Equipment	28.7	15.3 to 42.0

These are the values of A_i that provide the same average amount of profit as the current rules when the time value of money is correctly accounted for by using Eq. (14.6).¹

This report did not attempt to formally consider the question of what the optimal values of A_i should be. This is why the values implicit in the current regulations are used. However, three more speculative comments regarding these values will be made. First, the negative value for land reflects the fact that the current regulations underestimate the time value of money by ignoring compounding and using the treasury rate, which averages 1.5 percent below the risk-free rate. Perhaps policymakers would actually set A_i for land equal to 0 percent in the revised regulation. Second, it may be optimal to subdivide equipment into a number of smaller categories such as state-of-the-art machinery, old machinery, office equipment, etc. Then, different rates could be given to each subgroup for the reasons discussed in Sec. 11. In particular, only state-of-the-art machinery specifically designed for defense production would receive the phenomenally large return of 35 percent plus the risk-free rate. Third, there is some question whether the rates for buildings and especially equipment are higher than required.

The special treatment of R&D contractors with little facilities capital should be discontinued.

4. Other Unrecognized Costs

The regulations should contain a separate section for calculating profit meant as reimbursement for other unrecognized costs. The formula for calculating this is

$$\delta [E(\tilde{C}) + F] , \quad (14.7)$$

where δ is estimated by the contract officer. The normal value of δ should be 0.0055. The allowable range could conceivably be quite large and would probably include negative values. Further empirical work is required to set the allowable range.

The factors of management effort and employee talent should be specifically mentioned in the discussion of reasons why δ should be chosen higher or lower than average. If policymakers are able to

¹Recall that these values are derived in Sec. 11, Subsection F.

identify other important categories of other unrecognized costs these should also be included.

5. Incentives and Innovation

The regulations should contain a separate section for calculating profit meant as economic profit. The formula for calculating this is

$$e[E(\tilde{C}) + F] , \quad (14.8)$$

where e is estimated by the contract officer. According to Sec. 13, economic profit should have a normal value equal to

$$0.0162E(\tilde{C}) . \quad (14.9)$$

According to Eq. (13.11),

$$F = 0.15E(\tilde{C}) \quad (14.10)$$

for the typical contract. Therefore, the normal value of e should be chosen to satisfy

$$e[E(\tilde{C}) + 0.15E(\tilde{C})] = 0.0162E(\tilde{C}) . \quad (14.11)$$

Solving Eq. (14.11) yields

$$e = 0.0141 . \quad (14.12)$$

Therefore, a normal value of 0.0141 would be specified if a single normal value was specified for all sectors. However, as explained in Sec. 12, it would probably be better to specify a different normal values of e for different sectors of the industry depending on the perceived need for innovation in that sector. Section 12 suggested one procedure for doing this. Table 14.3 presents the values of e by sector generated by using this procedure.²

An allowable range would also be specified for each e_i . The key factor affecting whether a larger or smaller than normal value is selected

²These values are generated by substituting $e = 0.0141$ and the values of α_i from Table 12.1 into Eq. (12.9).

Table 14.3
Normal Values of Innovation
and Incentive Profit
by Sector
(in percent)

Sector	e_i
Aircraft	2.15
Missiles	0.88
Ships	0.05
Other weapons	0.68
Electronics	1.79
Other equipment	2.24
Services	0.17

should be the importance of innovation in the development of the product given its product type. For example, airplanes require more innovation than services. However, this is already compensated for by having the normal value of e_i be larger for the airplane sector than the service sector. For a given airplane, the relevant question for the adjustment factor is whether innovation plays a more important role in this airplane than in the typical airplane. Thus, a contract for an advanced new fighter would receive more profit than one for a standard transport plane.

Finally, incentive schemes mentioned in the current regulations that reward economic profit for observed actions on the part of the firm should be removed as discussed in Sec. 12.

6. The Deflation Factor

For cost-type contracts, the profit calculated in the above steps should be multiplied by the deflation factor D , given by the formula

$$D = \frac{E(\tilde{C})}{E(\tilde{C}) + \alpha F(1 - \omega)}, \quad (14.13)$$

where $E(\tilde{C})$ denotes expected costs, α is the progress payment rate, F is the financing cost, and ω is the risk parameter. All these parameters are estimated in previous components.

Appendix A

PROOF OF PROPOSITION 2

Mathematically, one can view the firm as signing n separate contracts where contract t only involves period t costs. That is, contract t is as follows.

Period 0: The contract (π_t, γ, α) is signed.

Period t : The realization of \tilde{C}_t given by C_t occurs. The firm spends C_t and immediately receives αC_t from government.

Period n : The firm receives $\pi_t + \gamma[E(\tilde{C}_t) - C_t]$ from government.

The procedure in the proof will be to calculate π_t for every t . Then π is simply given by

$$\pi = \sum_{t=1}^n \pi_t . \quad (A.1)$$

Consider contract t . First suppose that the firm is at time t and \tilde{C}_t is realized at some value C_t . Then, the value of the project is certain and is given by

$$v(C_t) = -(1-\alpha)C_t + \frac{\pi_t + E(\tilde{C}_t) + (1-\gamma)[C_t - E(\tilde{C}_t)] - \alpha C_t}{(1+r_F)^{t-1}} . \quad (A.2)$$

Then, by applying Proposition 1 t times to Eq. (A.2) and using Eqs. (4.4) and (4.7), one obtains the following value for the contract at time 0, denoted by $v_t(\pi_t, \gamma, \alpha)$.

$$v_t(\pi_t, \gamma, \alpha) = \frac{\pi_t - \gamma \mu_t E(\tilde{C}_t) - (1+\mu_t)(1-\alpha)F_t}{(1+r_F)^t} . \quad (A.3)$$

In the above expression, the variable F_t denotes the risk-neutral financing cost for this contract given by

$$F_t = E(\tilde{C}_t)z(\ell - t) . \quad (\text{A.4})$$

The required level of profit to yield a zero value for $v_t(\pi_t, \gamma, \alpha)$ is therefore given by

$$\pi_t = \gamma \mu_t E(\tilde{C}_t) + (1 + \mu_t)(1 - \alpha)F_t . \quad (\text{A.5})$$

Summation over t yields the required profit for the entire contract.

$$\pi = \gamma \sum_{t=1}^n \mu_t E(\tilde{C}_t) + (1 - \alpha) \sum_{t=1}^l (1 + \mu_t) F_t . \quad (\text{A.6})$$

Substitution of Eqs. (4.12) and (4.13) into Eq. (A.6) yields Eq. (4.14).

Appendix B

PROOF OF PROPOSITION 3

Define A_t and B_t as follows.

$$A_t = \sum_{i=1}^t a_i \quad (\text{B.1})$$

and

$$B_t = \sum_{i=1}^t b_i . \quad (\text{B.2})$$

The following lemma will be useful.

Lemma:

$$A_t \leq B_t \text{ for every } t \leq \ell .$$

Proof:

A_t and B_t are given by

$$A_t = \frac{\sum_{i=1}^t E(\tilde{C}_i)}{\sum_{i=1}^t E(\tilde{C}_i) + \sum_{i=t+1}^n E(\tilde{C}_i)} \quad (\text{B.3})$$

and

$$B_t = \frac{\sum_{i=1}^t E(\tilde{C}_i) z(i)}{\sum_{i=1}^t E(\tilde{C}_i) z(i) + \sum_{i=t+1}^n E(\tilde{C}_i) z(i)} . \quad (\text{B.4})$$

Rewrite B_t as

$$B_t = \frac{k_1 \sum_{i=1}^t E(\tilde{C}_i)}{k_1 \sum_{i=1}^t E(\tilde{C}_i) + k_2 \sum_{i=t+1}^n E(\tilde{C}_i)}, \quad (B.5)$$

where

$$k_1 = \frac{\sum_{i=1}^t E(\tilde{C}_i) z(i)}{\sum_{i=1}^t E(\tilde{C}_i)} \quad (B.6)$$

and

$$k_2 = \frac{\sum_{i=t+1}^n E(\tilde{C}_i) z(i)}{\sum_{i=t+1}^n E(\tilde{C}_i)}. \quad (B.7)$$

It is clearly sufficient to show that

$$\frac{k_2}{k_1} \leq 1. \quad (B.8)$$

From Eqs. (B.6) and (B.7),

$$\frac{k_2}{k_1} = \frac{\sum_{i=t+1}^n E(\tilde{C}_i) z(i)}{\sum_{i=t+1}^n E(\tilde{C}_i)} \times \frac{\sum_{i=1}^t E(\tilde{C}_i)}{\sum_{i=1}^t E(\tilde{C}_i) z(i)}. \quad (B.9)$$

Multiply the numerator and denominator of Eq. (B.9) by $1/z(t)$ to yield

$$\frac{k_2}{k_1} = \frac{\sum_{i=t+1}^n E(\tilde{C}_i) z(i)/z(t)}{\sum_{i=t+1}^n E(\tilde{C}_i)} \times \frac{\sum_{i=1}^t E(\tilde{C}_i)}{\sum_{i=1}^t E(\tilde{C}_i) z(i)/z(t)}. \quad (B.10)$$

Each fraction in Eq. (B.10) is clearly ≤ 1 . Q.E.D.

Now define Δ_i by

$$\Delta_i = \mu_i - \mu_{i-1} \quad (\text{B.11})$$

for $i \in \{2, \dots, n\}$. Then, ϕ and ψ can be rewritten as

$$\phi = \mu_1 + \sum_{i=2}^n \Delta_i A_{i-1} \quad (\text{B.12})$$

and

$$\psi = \mu_1 + \sum_{i=2}^n \Delta_i B_{i-1} \quad (\text{B.13})$$

The result now follows immediately. Q.E.D.

Appendix C

THE RELATIVE SIZES OF ϕ AND ψ

This appendix will calculate the relative size of ϕ and ψ for an example where costs are expected to be incurred uniformly. Continuous compounding will be used. Costs are expected to be incurred uniformly at a rate of $E(\bar{C})/\ell$ per year for ℓ years. The continuous risk-free rate will be denoted by r and the risk parameter at time t will be assumed to be given by

$$\mu(t) = \mu e^{\theta t} , \quad (C.1)$$

where θ is a nonnegative constant. Thus, risk is assumed to grow exponentially at a rate of θ per year.

For the case of continuous compounding, $a(t)$ is defined by

$$a(t) = \frac{1}{\ell} . \quad (C.2)$$

The function $b(t)$ is defined by

$$b(t) = \frac{e^{r(\ell-t)} - 1}{\int_0^\ell e^{r(\ell-t)} - 1 dt} . \quad (C.3)$$

Then, ϕ and ψ are defined by

$$\phi = \int_0^\ell a(t) \mu(t) dt \quad (C.4)$$

and

$$\psi = \int_0^\ell b(t) \mu(t) dt . \quad (C.5)$$

Substitution of Eqs. (C.1)–(C.3) into Eqs. (C.4) and (C.5) and reorganization yields

$$\frac{\phi}{\mu} = \frac{e^{\theta} - 1}{\theta} \quad (\text{C.6})$$

and

$$\frac{\psi}{\mu} = \begin{cases} \frac{e^{r\ell} \left\{ \frac{e^{(\theta-r)\ell} - 1}{(\theta-r)\ell} \right\} - \frac{e^{\theta\ell} - 1}{\theta\ell}}{\frac{e^{r\ell} - 1}{r\ell} - 1} & , \quad \theta \neq r \\ \frac{e^{\theta\ell} - \frac{e^{\theta\ell} - 1}{\theta\ell}}{\frac{e^{\theta\ell} - 1}{\theta\ell} - 1} & , \quad \theta = r . \end{cases} \quad (\text{C.7})$$

Table C.1 now displays the ratio of ψ to ϕ for various values of θ and ℓ when r is set equal to 10 percent. The values do not differ dramatically for small changes in r .

Table C.1

The Ratio ψ/ϕ for Various Values of ℓ and θ When $r = 0.1$

θ	ℓ			
	1	2	3	4
0	1	1	1	1
0.1	0.98	0.97	0.95	0.93
1	0.83	0.68	0.55	0.44
2	0.68	0.45	0.29	0.22

Appendix D

THE APPROXIMATE VALUE OF F WHEN COST INCURRENCE IS UNIFORM

Consider a contract that will last ℓ years. Total expected costs are $E(\tilde{C})$ and costs are expected to be incurred at the uniform rate of $E(\tilde{C})/\ell$ per year. Let R_F denote the annualized risk-free rate for all time periods. This appendix explains why the formula

$$F^a = R_F \frac{\ell}{2} E(\tilde{C}) \quad (D.1)$$

is an approximation for the risk-neutral financing cost and determines the nature and size of the error from using this approximation.

First, the correct value of F will be calculated. Consider the following two cash flows.

Cash Flow 1: Income is received at the rate $E(\tilde{C})/\ell$ per year for ℓ years from time 0 to time ℓ .

Cash Flow 2: $E(\tilde{C}) + y$ dollars is received at time ℓ .

Then, F is by definition the value of y such that a risk-neutral individual would be indifferent between the two cash flows.

This can be calculated as follows. Let r denote the instantaneous interest rate corresponding to R_F . It is given by

$$e^r - 1 = R_F . \quad (D.2)$$

Then the present discounted value of Cash Flow 1 calculated at time 0 is given by

$$V_1 = e^{r\ell} \int_0^\ell \frac{E(\tilde{C})}{\ell} e^{-rt} dt . \quad (D.3)$$

This can be rewritten as

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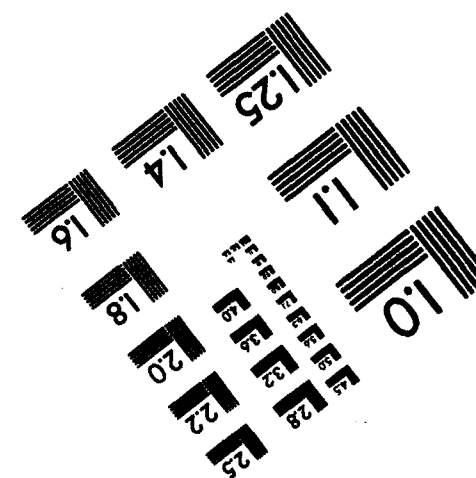
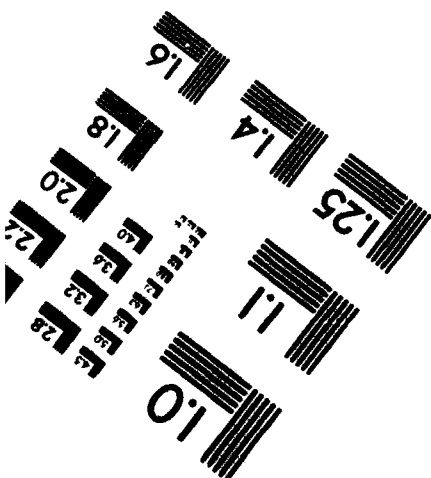
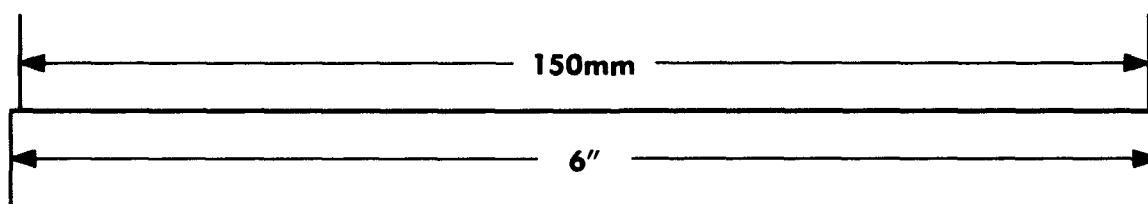
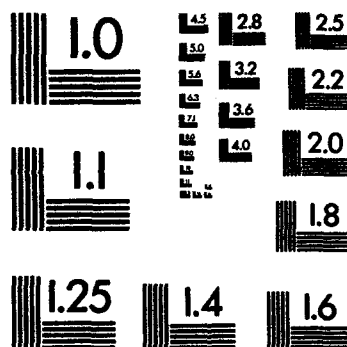
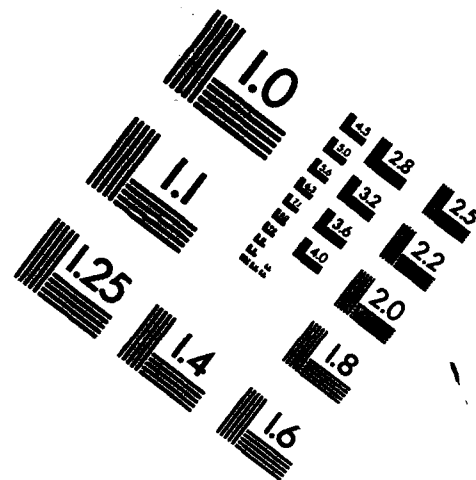
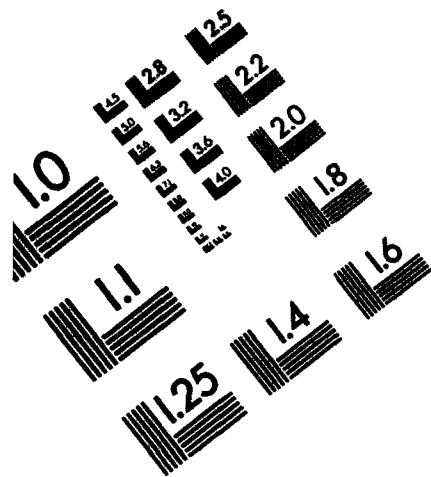
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$$V_1 = E(\tilde{C}) \frac{e^{r\ell} - 1}{r\ell} . \quad (D.4)$$

Of course, the present discounted value of Cash Flow 2 calculated at time ℓ is simply

$$V_2 = E(\tilde{C}) + y . \quad (D.5)$$

Setting Eq. (D.4) equal to Eq. (D.5) and solving for y yields the value of F . This is given by

$$F = E(\tilde{C})\theta(r, \ell) , \quad (D.6)$$

where

$$\theta(r, \ell) = \frac{e^{r\ell} - 1}{r\ell} - 1 . \quad (D.7)$$

Two methods for deriving Eq. (D.1) as an approximation will now be given. The first uses a Taylor series expansion. For any function $f(z)$, a second-order Taylor series approximation around z_0 is given by

$$T(z) = f(z_0) + f'(z_0)(z - z_0) + \frac{f''(z_0)(z - z_0)^2}{2} . \quad (D.8)$$

Therefore, a second-order Taylor series approximation of e^z around 0 is given by

$$T(z) = 1 + z + \frac{z^2}{2} . \quad (D.9)$$

Substitute this approximation into Eq. (D.7). This yields

$$\frac{r\ell}{2} . \quad (D.10)$$

Finally, the instantaneous rate r is very close to the annual rate R_F . Substituting R_F for r in Eq. (D.10) thus yields an approximation for θ that will be denoted by

$$\theta_a = \frac{R_F \ell}{2} . \quad (D.11)$$

Substitution of θ_a for θ in Eq. (D.6) yields Eq. (D.1).

The other way to derive Eq. (D.1) as an approximation is more intuitive. Namely, Eq. (D.1) is essentially the risk-free cost calculated using simple interest (i.e., ignoring the effects of compounding). Consider the value of Cash Flow 1 calculated at time ℓ as given by Eq. (D.3). Rewrite this as

$$V_1 = \int_0^{\ell} \frac{E(\tilde{C})}{\ell} e^{r(\ell-t)} dt . \quad (D.12)$$

Substitute Eq. (D.2) into Eq. (D.12) to yield

$$V_1 = \int_0^{\ell} \frac{E(C)}{\ell} (1 + R_F)^{(\ell-t)} dt . \quad (D.13)$$

This has a natural interpretation. At time t the individual receives money at the annual rate of $E(\tilde{C})/\ell$. The value of this flow at time ℓ is calculated by compounding at the annual rate of interest for $\ell - t$ years. Now, if one ignores the effects of compounding, the value $(1 + R_F)^{\ell-t}$ is replaced by $1 + R_F(\ell - t)$. Substitute this into Eq. (D.13). Let V_1^a denote this approximate value.

$$V_1^a = \int_0^{\ell} \frac{E(\tilde{C})}{\ell} \{1 + R_F(\ell - t)\} dt . \quad (D.14)$$

Integration of Eq. (D.14) and reorganization yields

$$V_1^a = E(\tilde{C}) + \frac{E(\tilde{C})R_F \ell}{2} . \quad (D.15)$$

Now set V_1^a equal to V_2 given by Eq. (D.5) to determine the approximate value of F .

Denote this by F^a .

$$E(\tilde{C}) + \frac{E(\tilde{C})R_F\ell}{2} = E(\tilde{C}) + F^a \quad (D.16)$$

Reorganize Eq. (D.16) to yield

$$F^a = \frac{R_F\ell}{2} E(\tilde{C}) \quad (D.17)$$

This is the approximation derived through using the Taylor series approximation.

Now the question of whether Eq. (D.1) is a good approximation will be addressed. Let $\varepsilon(\ell, R_F)$ denote the error in the firm's share of financing costs from using the approximation as a percentage of expected costs given the length ℓ and risk-free rate R_F . This is given by

$$\varepsilon(\ell, R_F) = \frac{(1 - \alpha)(F^a - F) \times 100\%}{E(\tilde{C})} \quad (D.18)$$

Substitution of Eqs. (D.1) and (D.6) into Eq. (D.18) yields

$$\varepsilon(\ell, A_F) = (1 - \alpha)(\theta_a - \theta) \times 100\% \quad (D.19)$$

Table D.1 presents values of ε for a range of values of ℓ and R_F for $\alpha = 0.8$. For contracts shorter than two years, the approximation actually overestimates the true financing cost because an annual interest rate is used on a length of time less than a year.¹ However, the error is

Table D.1

**Values of $\varepsilon(\ell, R_F)$
(in percent)**

R_F	ℓ					
	0.5	1	2	3	4	5
0.04	0.00	0.00	-0.01	-0.02	-0.05	-0.10
0.08	0.01	0.01	-0.02	-0.10	-0.22	-0.39
0.12	0.02	0.02	-0.05	-0.22	-0.50	-0.91
0.16	0.04	0.04	-0.09	-0.39	-0.91	-1.65

¹That is, the interest on a period of time t less than one year is calculated as $R_F t$. It should be calculated as $(1 + R_F)^t - 1$. For $t < 1$ the latter term is smaller than the former.

extremely trivial. For contracts two years long or longer the approximation underestimates the true financing cost, because the approximation ignores the effects of compounding. The effects are greater for higher interest rates or longer contracts. Therefore, the extent of the underestimation is greatest in the lower right-hand corner of the table. All the errors are quite small, especially for the plausible cases of contracts of four years or less.

Therefore, formula (D.1) will often be used in the text to develop "ballpark" estimates of the size of financing cost expressed as a percentage of expected cost. It will also be suggested for use as the "simple formula" for calculating working capital costs on short or small dollar value contracts.

Appendix E

PROOF OF PROPOSITION 5

Let $\Gamma(\pi)$ denote the increased value of the contract to a risk-neutral individual calculated at time n , which occurs when government decides to make progress payments on profits. This is given by

$$\Gamma(\pi) = \alpha\pi \sum_{t=1}^n \frac{E(\tilde{C}_t)}{E(\tilde{C})} z(t) , \quad (E.1)$$

where $z(t)$ is defined by Eq. (4.9).

It is straightforward to redo the analysis of App. A to derive the new rule for calculating minimum profits. It is given by

$$\pi + \Gamma(\pi)(1 - \psi) = \gamma\phi E(\tilde{C}) + (1 + \psi)(1 - \alpha)F . \quad (E.2)$$

This rule has a natural economic interpretation. Note that the right-hand sides of Eqs. (4.14) and (E.2) are identical. Progress payments on profit are somewhat risky because they are tied to random levels of cost incurrence. Thus, although a risk-neutral individual is Γ dollars better off when progress payments are paid on profit, the firm is only $(1 - \psi)\Gamma$ dollars better off. Thus $\pi + \Gamma(1 - \psi)$ is the present discounted value (adjusted for risk) of the profit stream. Thus, the general rule is that the risk-adjusted present discounted value of profits must equal the right-hand side of Eqs. (4.13) and (E.2). In the case of Sec. 4, where no progress payments on profit were given, the risk-adjusted present discounted value simply equals π . However, when progress payments are given, this value is somewhat larger and is given by the left-hand side of Eq. (E.2).

Substitution of Eq. (4.11) into Eq. (E.1) yields

$$\Gamma(\pi) = \frac{\alpha\pi F}{E(\tilde{C})} . \quad (E.3)$$

Substitution of Eq. (E.3) into Eq. (E.2) and reorganizations yields Eq. (9.3). Q.E.D.

Appendix F

PROOF OF PROPOSITION 6

First, two lemmas will be stated. Then these lemmas will be used to prove the proposition.

Lemma 1:

For every $\ell \in \{1, 2, 3, \dots\}$, Eq. (11.6) can be equivalently written as

$$\pi_K = (R_F + A)K \left\{ \frac{(1 + R_F)^\ell - 1}{R_F} \right\}. \quad (\text{F.1})$$

Proof:

Equation (11.6) equals Eq. (F.1) if and only if

$$\sum_{t=1}^{\ell} (1 + R_F)^{\ell-t} = \frac{(1 + R_F)^\ell - 1}{R_F}. \quad (\text{F.2})$$

Therefore, it is sufficient to show that Eq. (F.2) is true. This will be done.

Let χ denote $(1 + R_F)$. Then Eq. (F.2) can be rewritten as

$$(\chi - 1) \sum_{t=0}^{\ell-1} \chi^t = \chi^\ell - 1. \quad (\text{F.3})$$

The left-hand side of Eq. (F.3) will now be evaluated and shown to be equal to the right-hand side of Eq. (F.3). The left-hand side of Eq. (F.3) equals

$$\sum_{t=0}^{\ell-1} \chi^{t+1} - \chi^t, \quad (\text{F.4})$$

which equals

$$\chi' - 1. \quad (\text{F.5})$$

Q.E.D.

Lemma 2:

Let \tilde{X} , \tilde{Y} , and \tilde{Z} be three random variables and let $f(\tilde{X}, \tilde{Y})$ be a function of the first two. Assume that \tilde{X} is independent of \tilde{Y} and \tilde{Z} . Then

$$\text{cov}(f(\tilde{X}, \tilde{Y}), \tilde{Z}) = \text{cov}(E_{\tilde{X}} f(\tilde{X}, \tilde{Y}), \tilde{Z}), \quad (\text{F.6})$$

where $E_{\tilde{X}}$ denotes the expectation over \tilde{X} .

Proof:

The proof simply applies the definition of the covariance function in a straightforward manner. Therefore, it will not be presented. Q.E.D.

Now, first consider a slightly simpler problem, namely, that the firm is in period 0 and is attempting to win a contract. Suppose that $\tilde{\theta}_1$ and \tilde{R}_M^1 are not yet known. Then let v denote the present discounted value calculated at time ℓ of the firm's income flows from this single attempt to win a contract (i.e., of its income flows from time 0 to ℓ). It is clear that the present discounted value of the entire project, V , is given by

$$V = -K + \frac{v}{\Gamma}, \quad (\text{F.7})$$

where Γ is the ℓ -year risk-free rate, i. e.,

$$\Gamma = (1 + R_F)^\ell. \quad (\text{F.8})$$

Therefore, V can be calculated by first calculating v . This will now be done.

If the firm wins the contract it receives d dollars in period t . To apply the CAPM it will be useful to view the random process determining the firm's income in a slightly artificial fashion. The random variable $\tilde{\theta}_1$ is of course the random variable determining $\tilde{\theta}_1$, the probability that the firm wins the contract. Now let \tilde{u} denote a uniform random variable over $[0, 1]$ distributed independently of $\tilde{\theta}_1$. Then the firm's income can be viewed as being determined by the function $f(\tilde{\theta}_1, \tilde{u})$ defined by

$$f(\tilde{\theta}_1, \tilde{u}) = \begin{cases} d, & \tilde{u} \leq \tilde{\theta}_1 \\ 0, & \tilde{u} > \tilde{\theta}_1 \end{cases} \quad (\text{F.9})$$

Therefore, v is given by

$$v = E(f(\tilde{\theta}_1, \tilde{u})) - \lambda \text{cov}(f(\tilde{\theta}_1, \tilde{u}), \tilde{R}_M^1) \quad (\text{F.10})$$

Since \tilde{u} is independent of $\tilde{\theta}_1$ and \tilde{R}_M^1 , Eq. (F.6) can be applied. Doing this and reorganizing yields

$$v = d\{E - \lambda \sigma\} \quad (\text{F.11})$$

or, equivalently,

$$v = dv \quad (\text{F.12})$$

Substitution of Eq. (F.12) into Eq. (F.7) yields

$$V = -K + \frac{dv}{\Gamma} \quad (\text{F.13})$$

The value of π_K is equal to the value of d such that Eq. (F.13) equals zero. This is given by

$$\pi_K = \frac{\Gamma K}{v} \quad (\text{F.14})$$

Substitute Eq. (F.8) into Eq. (F.14) and reorganize to yield

$$\pi_K = \frac{R_F K}{v} \left\{ \frac{(1 + R_F)^t - 1}{R_F} \right\} \quad (\text{F.15})$$

Substitute Eq. (11.5) into Eq. (F.15) and reorganize to yield

$$\pi_K = (R_F + A) \left\{ \frac{(1 + R_F)^t - 1}{R_F} \right\}, \quad (\text{F.16})$$

which equals Eq. (F.1). Therefore, by Lemma 1 we are done. Q.E.D.

Appendix G

THE TERM STRUCTURE OF THE LIBOR FUTURES RATES

This appendix will examine historical data to determine typical values for the parameters $\{\delta_t\}$. The pattern of the $\{\delta_t\}$ parameters is often referred to as the term structure of interest rates. Ideally one would like to examine 15 or 20 years of data to calculate average values and assess the nature of plausible variations from the average. Unfortunately, the LIBOR futures market is relatively new. It has been in existence since 1985 and futures contracts three years into the future have been traded only since July 1987. Table G.1 presents the value of the LIBOR and the 12 futures rates for the beginning of each quarter for the last two quarters of 1987 and the four quarters of 1988.¹ The averages across all six periods are also presented. Table G.2 presents the associated values of δ_t .

Notice that δ_t is strictly increasing in t for every period; i.e., the LIBOR futures rates increase for periods further in the future. Two factors affect the LIBOR futures rates. Because of interest rate risk they tend to rise. (A firm must pay a premium to guarantee that it will be able to borrow at a fixed rate in some future time period.) This underlying rising trend will be strengthened or diminished depending on whether the market expects the LIBOR to rise or fall. It is quite rare for expectations of falling rates to be so strong that the LIBOR futures rates actually fall. Thus, the LIBOR futures rates will typically rise for periods further in the future.

It will be useful to develop three different sets of values for the δ_t parameters to examine the behavior of the proposed rule. Denote these by $\{\delta_t^*\}$, $\{\underline{\delta}_t\}$, and $\{\bar{\delta}_t\}$. Let $\{\delta_t^*\}$ represent typical or average values. Let $\{\underline{\delta}_t\}$ represent values that exhibit the most extreme decrease in t that we are likely to see in a 10- or 15-year period. Let $\{\bar{\delta}_t\}$ represent values that exhibit the most extreme increase in t that we are likely to see in a 10- or 15-year period.

¹LIBOR for deposits of other maturities also exist. However, futures contracts are written solely on the three-month LIBOR. Therefore, the three-month rate is the one of interest for this report.

Table G.1
The Current LIBOR and LIBOR Futures Rates
(in percent)

	July 1987	October 1987	January 1988	April 1988	July 1988	October 1988	Average
Current							
LIBOR	7.1875	8.375	7.4375	6.9375	7.9375	8.625	7.75
3 months	7.42	8.6	7.56	7.28	7.96	8.78	7.93
6 months	7.69	8.98	7.8	7.58	8.3	8.66	8.17
9 months	7.91	9.26	8.14	7.87	8.48	8.79	8.41
12 months	8.11	9.47	8.48	8.13	8.64	8.96	8.63
15 months	8.29	9.63	8.77	8.35	8.78	9.13	8.83
18 months	8.49	9.78	9.02	8.55	8.89	9.11	8.97
21 months	8.67	9.91	9.22	8.73	8.98	9.18	9.12
24 months	8.83	10.04	9.39	8.88	9.06	9.25	9.24
27 months	8.98	10.15	9.53	9.02	9.14	9.33	9.36
30 months	9.12	10.25	9.65	9.14	9.21	9.34	9.45
33 months	9.26	10.34	9.76	9.24	9.29	9.4	9.55
36 months	9.39	10.42	9.86	9.34	9.37	9.44	9.64

NOTE: All rates are for the first business day of the month as quoted in the *Wall Street Journal*. The "current LIBOR" is the quoted rate for three-month deposits. The "t month" rate is the futures rate for a contract that depends on the LIBOR t months from the current date.

Table G.2
The Values of δ_t
(in percent)

	July 1987	October 1987	January 1988	April 1988	July 1988	October 1988	Average
3 months	0.23	0.22	0.12	0.34	0.02	0.15	0.18
6 months	0.5	0.6	0.36	0.64	0.36	0.03	0.42
9 months	0.72	0.88	0.7	0.93	0.54	0.16	0.66
12 months	0.92	1.09	1.04	1.19	0.7	0.33	0.88
15 months	1.1	1.25	1.33	1.41	0.84	0.5	1.08
18 months	1.3	1.4	1.58	1.61	0.95	0.48	1.22
21 months	1.48	1.53	1.78	1.79	1.04	0.55	1.37
24 months	1.64	1.66	1.95	1.94	1.12	0.62	1.49
27 months	1.79	1.77	2.09	2.08	1.2	0.7	1.61
30 months	1.93	1.87	2.21	2.2	1.27	0.71	1.7
33 months	2.07	1.96	2.32	2.3	1.35	0.77	1.8
36 months	2.2	2.04	2.42	2.4	1.43	0.81	1.89

The average values reported in the last column of Table G.2 are the natural candidate for $\{\delta_t^*\}$. Although six quarters may give marginally enough data to develop an average value for the $\{\delta_t\}$ parameters,

that is clearly not enough to develop plausible extreme values for them. Even over the six quarters of data available, the values have varied quite significantly. For example, δ_{12} varied between 0.81 percent and 2.42 percent. However, we would surely expect even larger variations over a 10- or 15-year period.

It is probably the case that the term structure of the interest rates on government debt closely follows the term structure of the LIBOR. Table G.3 presents the difference between the rate on five-year government bonds and the one-month T-bill, which can be calculated from Table 2.1. This difference is probably in general quite close to the value of δ_{12} . For example, in one data point of overlap between Table G.2 and G.3, the value of δ_{12} is 2.2 percent and the difference between the five-year and one-year rate is 2.51 percent. Thus, to develop at least a rough idea of how we might expect the values of δ_t to vary over a 10- or 15-year period, it will be assumed that plausible extreme values for δ_{12} are given by the extreme values of the differences in Table G.3. That is, $\bar{\delta}_{12}$ equals 3.94 percent and $\underline{\delta}_{12}$ equals -0.61 percent. Then, the values for previous periods will be

Table G.3
The Difference Between the Five-Year Government
Bond Yield and the One-Month T-Bill Rate
(in percent)

Date	Difference	Date	Difference
1971 July	1.72	1980 July	3.41
1972 January	1.52	1981 January	-0.47
1972 July	1.47	1981 July	-0.61
1973 January	1.00	1982 January	3.94
1973 July	-0.20	1982 July	-0.20
1974 January	0.96	1983 January	1.97
1974 July	-0.35	1983 July	2.43
1975 January	0.11	1984 January	1.86
1975 July	1.90	1984 July	2.44
1976 January	1.64	1985 January	2.72
1976 July	1.53	1985 July	2.32
1977 January	2.32	1986 January	1.77
1977 July	1.59	1986 July	0.86
1977 January	1.69	1987 January	1.69
1978 July	1.43	1987 July	2.51
1979 January	-0.69	Average	1.35
1979 July	-0.77	Minimum	-0.61
1980 January	0.90	Maximum	+3.94

generated by assuming that the proportional relationships between periods in $\{\delta_t^*\}$ continue to hold. Formally, these are defined by

$$\bar{\delta}_t = \frac{\bar{\delta}_{12}\delta_t^*}{\delta_{12}^*} \quad (\text{G.1})$$

and

$$\underline{\delta}_t = \frac{\underline{\delta}_{12}\delta_t^*}{\delta_{12}^*} \quad (\text{G.2})$$

for $t < 12$. The values for the three estimates of the δ_t parameters are reported in Table G.4.

Table G.4

**Values of $\underline{\delta}_t$, δ_t^* , and $\bar{\delta}_t$
(in percent)**

t	$\underline{\delta}_t$	δ_t^*	$\bar{\delta}_t$
1	-0.06	0.18	0.38
2	-0.14	0.42	0.88
3	-0.21	0.66	1.38
4	-0.28	0.88	1.83
5	-0.35	1.08	2.25
6	-0.39	1.22	2.54
7	-0.44	1.37	2.86
8	-0.48	1.49	3.10
9	-0.52	1.61	3.36
10	-0.55	1.70	3.54
11	-0.58	1.80	3.75
12	-0.61	1.89	3.94

Appendix H

THE ERROR FROM USING A TIME-INVARIANT RISK-FREE RATE

As explained in Subsection D of Sec. 7, a time-invariant risk-free rate can be calculated for any given time pattern of cost incurrence and contract length. However, the time-invariant risk-free rate depends on these two factors. In particular, for the typical case where the risk-free rates rise in future periods, the correct time-invariant rate is larger for longer contracts or contracts where a greater fraction of costs are incurred near the end of the contract. Thus, if the regulations were to specify a single time-invariant rate, the best that could be done would be to specify a rate that was exactly correct for a contract of typical length with a typical pattern of cost incurrence. The regulations would then overcompensate shorter contracts and contracts where more cost was incurred in earlier periods and undercompensate longer contracts and contracts where more cost was incurred in later periods.

This appendix roughly quantifies the size of this error, which, of course, depends on how fast the δ_t parameters increase or decrease. If δ_t is constant, then it is perfectly correct to use a time-invariant rate and there is no error. However, as δ_t increases or decreases more rapidly, then so should the risk-free rates, and the error from using constant rate increases. Therefore, the size of the error will be calculated for the three different values of δ_t determined in App. G to calculate the size of the typical error as well as the plausible extreme values of the errors.

Two calculations will be performed to estimate the size of these errors. It will be assumed for both calculations that the regulations use a time-invariant rate determined by calculating the rate that would be correct for a three-year contract when costs are expected to be uniformly incurred. First the error that results from using this rate on contracts of differing lengths (maintaining the assumption of uniform expected cost incurrence) will be calculated. Second, the error that results from using this rate when all costs are expected to be incurred in a single period (maintaining the assumption of a three-year length) will be calculated.

First, consider variations in contract length. Table H.1 presents the value of Δ calculated by Eq. (7.26) for the case of uniform cost incurrence for the three sets of values for δ_t . Let $\Delta^*(n, u)$ ($\underline{\Delta}(n, u)$, $\bar{\Delta}(n, u)$) denote the value of Δ for a contract of length n using the parameters δ_t^* ($\underline{\delta}_t$, $\bar{\delta}_t$) when expected cost incurrence is uniform.¹

Thus, for the typical values, $\{\delta_t^*\}$, the time-invariant risk-free rate on a three-month contract should be only 0.18 percent above the firm's current short-term borrowing rate, whereas the time-invariant rate on a five-year contract should be 1.73 percent above the firm's current short-term borrowing rate. If the regulations published a single rate equal to 1.47 percent above the firm's current rate (which is perfectly correct for a three-year contract), then a five-year contract would receive a rate that was 0.25 percent too low. The size of the errors would be much larger for the extreme increasing values, $\{\bar{\delta}_t\}$, since the risk-free rates increase more rapidly. The sign of the errors would be reversed for the extreme decreasing values, $\{\underline{\delta}_t\}$.

Table H.1
Values of Δ Given Uniform Cost Incurrence
(in percent)

n	Length in Years (<i>t</i>)	$\underline{\Delta}(n, u)$	$\Delta^*(n, u)$	$\bar{\Delta}(n, u)$
1	1/4	-0.06	0.18	0.38
2	1/2	-0.11	0.34	0.71
3	3/4	-0.16	0.50	1.05
4	1	-0.21	0.65	1.36
5	1-1/4	-0.26	0.79	1.66
6	1-1/2	-0.29	0.92	1.91
7	1-3/4	-0.33	1.03	2.15
8	2	-0.36	1.13	2.36
9	2-1/4	-0.40	1.23	2.56
10	2-1/2	-0.42	1.31	2.74
11	2-3/4	-0.45	1.39	2.91
12	3	-0.47	1.47	3.07
13	3-1/4	-0.49	1.53	3.19
14	3-1/2	-0.51	1.58	3.29
15	3-3/4	-0.52	1.62	3.37
16	4	-0.53	1.65	3.44
17	4-1/4	-0.54	1.68	3.49
18	4-1/2	-0.55	1.70	3.54
19	4-3/4	-0.55	1.72	3.58
20	5	-0.56	1.73	3.62

¹For this calculation it was assumed that $\delta_t = \delta_{12}$ for values of t larger than δ_{12} .

Furthermore, they would be quite small in absolute value, since the values $\{\delta_t\}$ do not decrease very fast.

Are these errors large? Perhaps the best way to develop a feel for this is to calculate the error as a percentage of expected costs. This can be roughly estimated as follows. Ignoring the effects of compounding, the correctly calculated risk-free financing cost for a contract with uniform cost incurrence n periods long is given by²

$$F(n) = R_F(n, u) \frac{n}{8} E(\tilde{C}) , \quad (H.1)$$

where $R_F(n, u)$ is the time-invariant annualized risk-free rate when cost incurrence is uniform as calculated above. Suppose that the financing cost for a contract of length n is actually calculated by using the time-invariant rate for a contract \hat{n} periods long. This would yield an answer of

$$G(n, \hat{n}) = R_F(\hat{n}, u) \frac{n}{8} E(\tilde{C}) . \quad (H.2)$$

Let $\epsilon(n, \hat{n})$ denote the error in profit paid to the firm expressed as a percentage of expected cost created by using G instead of F . The firm bears only $(1 - \alpha)$ of these costs itself and is thus compensated only for $(1 - \alpha)$ of the financing cost. Therefore, the error in the payment to the firm will be $(1 - \alpha)$ of the total error. Therefore, $\epsilon(n, \hat{n})$ is defined by

$$\epsilon(n, \hat{n}) = \frac{(1 - \alpha)[G(n, \hat{n}) - F(n)]}{E(\tilde{C})} \times 100\% . \quad (H.3)$$

Substitution of Eqs. (7.25), (H.1), and (H.2) into Eq. (H.3) yields

$$\epsilon(n, \hat{n}) = (1 - \alpha) \{ \Delta(\hat{n}, u) - \Delta(n, u) \} \frac{n}{8} \times 100\% . \quad (H.4)$$

Tables H.2 to H.4 present the values of ϵ for \hat{n} equal to 8, 10, and 12 (lengths in years of 2, 2-1/2, and 3) and for $\alpha = 0.8$. The first (second, third) column gives the errors when the term structure of the risk-free rates is given by $\delta_t, (\bar{\delta}_t^*, \bar{\delta}_t)$. The symbols $\epsilon^*, \underline{\epsilon}$, and $\bar{\epsilon}$ will be

²This is discussed in App. D.

Table H.2
Values of $\varepsilon(n, 8)$
(in percent)

n	Length in years	$\varepsilon(n, 8)$	$\varepsilon^*(n, 8)$	$\bar{\varepsilon}(n, 8)$
1	1/4	-0.01	0.02	0.05
2	1/2	-0.01	0.04	0.08
3	3/4	-0.02	0.05	0.10
4	1	-0.02	0.05	0.10
5	1-1/4	-0.01	0.04	0.09
6	1-1/2	-0.01	0.03	0.07
7	1-3/4	-0.01	0.02	0.04
8	2	0	0	0
9	2-1/4	0.01	-0.02	-0.05
10	2-1/2	0.02	-0.05	-0.10
11	2-3/4	0.02	-0.07	-0.15
12	3	0.03	-0.10	-0.21
13	3-1/4	0.04	-0.13	-0.27
14	3-1/2	0.05	-0.16	-0.33
15	3-3/4	0.06	-0.18	-0.38
16	4	0.07	-0.21	-0.43
17	4-1/4	0.08	-0.23	-0.48
18	4-1/2	0.09	-0.26	-0.53
19	4-3/4	0.09	-0.28	-0.58
20	5	0.10	-0.30	-0.63

used to denote ε when it is calculated by setting Δ equal to, respectively, Δ^* , $\underline{\Delta}$, and $\bar{\Delta}$. Errors for contracts of length one period to 20 periods (three months to five years) are calculated. In reality, probably very few contracts lasting longer than four years are signed where no deliveries occur until the end. Thus, considering the effects on contracts up to five years long is clearly more than adequate. The values in Table H.4 are also reported in Table 7.2.

For the typical case (given by the columns labeled ε^*), using a single time-invariant rate overcompensates short contracts and undercompensates long contracts as predicted. The effects are more severe for the case where the $\bar{\delta}_t$ parameters are used, because the risk-free rates should rise much more quickly. The effects are reversed in sign for the case where the $\hat{\delta}_t$ parameters are used because now the risk-free rates should fall over time. The errors from using $\hat{\delta}_t$ are smaller in absolute value than the other two cases because the $\hat{\delta}_t$ parameters are nearly constant. The errors are largest in absolute value for the $\bar{\delta}_t$ parameters.

Table H.3
Values of $\varepsilon(n, 10)$
(in percent)

n	Length in years	$\underline{\varepsilon}(n, 10)$	$\varepsilon^*(n, 10)$	$\bar{\varepsilon}(n, 10)$
1	1/4	-0.01	0.03	0.06
2	1/2	-0.02	0.05	0.10
3	3/4	-0.02	0.06	0.13
4	1	-0.02	0.07	0.14
5	1-1/4	-0.02	0.07	0.14
6	1-1/2	-0.02	0.06	0.12
7	1-3/4	-0.02	0.05	0.10
8	2	-0.01	0.04	0.08
9	2-1/4	0	0.02	0.04
10	2-1/2	0	0	0
11	2-3/4	0.01	-0.02	-0.05
12	3	0.01	-0.05	-0.10
13	3-1/4	0.02	-0.07	-0.15
14	3-1/2	0.03	-0.09	-0.19
15	3-3/4	0.04	-0.12	-0.24
16	4	0.04	-0.14	-0.28
17	4-1/4	0.05	-0.16	-0.32
18	4-1/2	0.06	-0.18	-0.36
19	4-3/4	0.06	-0.19	-0.40
20	5	0.07	-0.21	-0.44

Two conclusions can be drawn from these calculations. First, all of the errors are very small. The largest error on any of the tables is 0.63 percent of expected cost. By setting $\hat{n} = 12$, the largest error is reduced to 0.28 percent of cost and this is for the implausible case of a five-year contract. If we restrict ourselves to contracts of four years or less, the largest error in Table H.4 is 0.15 percent of cost. It seems reasonable to assume that errors of this magnitude will be relatively insignificant given estimating uncertainties.

Second, note that the errors for short contracts are extremely small even when $\hat{n} = 12$, because the risk-free financing cost is a relatively trivial fraction of expected cost on a short contract. Thus, even relatively large errors in calculating the risk-free financing cost represent a trivial percentage of expected cost for a short contract. Therefore, it is much more important to correctly estimate the risk-free financing cost for longer contracts. In particular, even if one thought that the average contract lasted two years it might be better to choose \hat{n} equal to three years to reduce the errors created in calculating the financing

Table H.4
Values of $\varepsilon(n,12)$
(in percent)

n	Length in Years	$\varepsilon(n,12)$	$\varepsilon^*(n,12)$	$\bar{\varepsilon}(n,12)$
1	1/4	-0.01	0.03	0.07
2	1/2	-0.02	0.06	0.12
3	3/4	-0.02	0.07	0.15
4	1	-0.03	0.08	0.17
5	1-1/4	-0.03	0.09	0.18
6	1-1/2	-0.03	0.08	0.17
7	1-3/4	-0.02	0.08	0.16
8	2	-0.02	0.07	0.14
9	2-1/4	-0.02	0.05	0.11
10	2-1/2	-0.01	0.04	0.08
11	2-3/4	0.01	0.02	0.04
12	3	0	0	0
13	3-1/4	0.01	-0.02	-0.04
14	3-1/2	0.01	-0.04	-0.08
15	3-3/4	0.02	-0.06	-0.11
16	4	0.02	-0.07	-0.15
17	4-1/4	0.03	-0.09	-0.18
18	4-1/2	0.04	-0.10	-0.21
19	4-3/4	0.04	-0.12	-0.24
20	5	0.05	-0.13	-0.28

costs of longer contracts. This effect is clearly illustrated in Tables H.2 to H.4. Even when \hat{n} equals three years, the error on a four-year contract is approximately double that of a three-month contract.

Now the second source of errors will be investigated—variations in the pattern of cost incurrence. It will be assumed that a three-year contract is being considered and that the time-invariant rate used by the regulations is determined by calculating the correct rate given that costs are expected to be incurred uniformly. However, the extreme assumption that all costs are actually incurred in a single period will be made. Let $\Delta(n,t)$ ($\Delta^*(n,t)$; $\bar{\Delta}(n,t)$) denote the value of Δ when the contract is of length n and all costs are incurred in period t where the δ_t parameters are given by $\delta_t^*(\delta_t^*; \bar{\delta}_t)$. Table H.5 presents the values of $\Delta(12,t)$, $\Delta^*(12,t)$, and $\bar{\Delta}(12,t)$, for values of t from 1 through 12. These are the correct values for the time-invariant rate. The rates the regulations use are $\Delta(12,u)$, $\Delta^*(12,u)$, and $\bar{\Delta}(12,u)$, depending on which case is being considered. These are given in Table H.1.

Table H.5

**Values of Δ When All Costs Are
Incurred in Period t for a Contract
12 Periods Long
(in percent)**

t	$\Delta(12, t)$	$\Delta^*(12, t)$	$\bar{\Delta}(12, t)$
1	-0.38	1.19	2.49
2	-0.41	1.28	2.68
3	-0.44	1.37	2.86
4	-0.47	1.45	3.02
5	-0.49	1.52	3.17
6	-0.51	1.58	3.30
7	-0.53	1.64	3.43
8	-0.55	1.70	3.54
9	-0.57	1.75	3.65
10	-0.58	1.80	3.74
11	-0.60	1.85	3.85
12	-0.61	1.89	3.94

As before, probably the best way to assess the significance of the errors thus created is to calculate the error as a percentage of cost. Following the procedure of the first case, the correct financing cost when all costs are incurred in period t is approximately given by

$$F(t) = R_F(12, t)(13 - t)E(\bar{C}) , \quad (\text{H.5})$$

where $R_F(12, t)$ is the correct invariant risk-free rate for a contract 12 periods long where all costs are incurred in period t . The actual value calculated by the regulations is

$$G(t) = R_F(12, u)(13 - t)E(\bar{C}) , \quad (\text{H.6})$$

where $R_F(12, u)$ is the correct invariant rate for a 12-period contract where expected cost is uniform. Define $\varepsilon(t)$ to be the error in the firm's payment as a percentage of expected cost. It is given by

$$\varepsilon(t) = \frac{(1 - \alpha)\{G(t) - F(t)\}}{E(\bar{C})} \times 100\% . \quad (\text{H.7})$$

Substitution of Eqs. (7.25), (H.5), and (H.6) into Eq. (H.7) yields³

$$\varepsilon(t) = (1 - \alpha)[\Delta(12, u) - \Delta(12, t)](13 - t) \times 100\% . \quad (\text{H.8})$$

Table H.6 presents the values of $\varepsilon(t)$ for $\alpha = 0.8$. As usual, the largest errors are created for the case of $\bar{\delta}_t$. However, the largest error is -0.52 percent of expected cost, which is quite small. Furthermore, the cases being considered where literally all costs are incurred in a single period are quite extreme. Less-extreme deviations from uniform cost incurrence would generate even smaller errors.

Table H.6

**Values of $\varepsilon(t)$
(in percent)**

t	$\underline{\varepsilon}(t)$	$\varepsilon^*(t)$	$\bar{\varepsilon}(t)$
1	0	0.01	0.03
2	-0.01	0.02	0.04
3	0	0.01	0.03
4	0	0	0.01
5	0.01	-0.01	-0.03
6	0.01	-0.03	-0.07
7	0.02	-0.06	-0.13
8	0.03	-0.09	-0.19
9	0.04	-0.13	-0.26
10	0.05	-0.17	-0.34
11	0.07	-0.21	-0.43
12	0.08	-0.25	-0.52

³As before, let ε^* , $\underline{\varepsilon}$, and $\bar{\varepsilon}$ denote the value of ε when ε is equal to, respectively, Δ^* , $\underline{\Delta}$, and $\bar{\Delta}$.

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